Rothamsted Experimental Station
Harpenden

LAWES AGRICULTURAL TRUST

REPORT

for

1947

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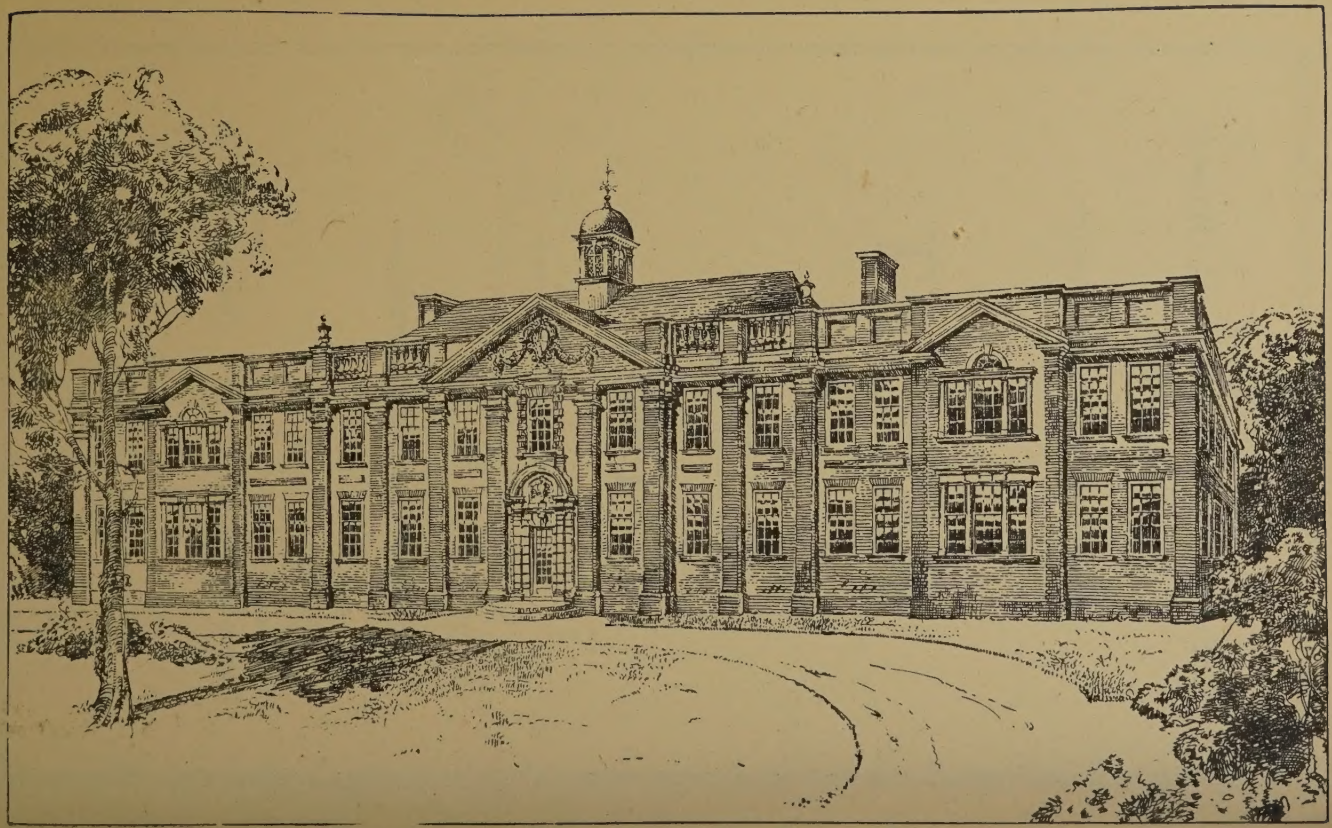

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914-1915.

CONTENTS

	Page
The Lawes Agricultural Trust	5
The Incorporated Society for extending the Rothamsted Experiments	5
Staff of the Rothamsted Experimental Station	6
Staff of the Soil Survey of England and Wales	12
Staff of the Woburn Experimental Station	12
Staff of the Imperial College of Science and Technology —Research Institute of Plant Physiology	12
The Imperial Bureau of Soil Science	13
Preface	14
Introduction. By the Director	16
Departmental Reports	
PHYSICS. By R. K. SCHOFIELD	21
CHEMISTRY. By E. M. CROWTHER	25
MICROBIOLOGY. By H. G. THORNTON	33
PEDOLOGY. By A. MUIR	37
BOTANY. By WINIFRED E. BRENCHLEY	39
CROP PHYSIOLOGY. By H. V. GARNER	43
STATISTICS. By F. YATES	44
PLANT PATHOLOGY. By F. C. BAWDEN	49
BIOCHEMISTRY. By N. W. PIRIE	53
ENTOMOLOGY. By C. B. WILLIAMS	56
BEES. By C. G. BUTLER	60
INSECTICIDES AND FUNGICIDES. By C. POTTER	63
FIELD EXPERIMENTS. By H. V. GARNER	74
THE FARMS. By J. R. MOFFATT	82
WOBURN EXPERIMENTAL STATION. By H. H. MANN ...	91
Special Reviews	
THE ELECTRIC CHARGE ON SOIL PARTICLES. By R. K. SCHOFIELD	95
REVIEW OF WORK ON POTATO VIRUS DISEASES	101
Departmental Publications	107

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The Incorporated Society for Extending the Rothamsted Experiments in Agricultural Science

The purpose of this Society is to collect funds for continuing and extending the work of the Rothamsted Station.

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E. W. Russell, M.A., Ph.D., A.I.B.A.E., F.Inst.P.

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M. L. Puri, M.Sc.

Assistant Staff ... ... — W. C. Game, I. Long, Josephine Noond, Jessie A. J. Walker, Monica Waller

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Head of Department	...	Winifred E. Brenchley, D.Sc., F.L.S.
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Voluntary Worker	...	A. K. Wafa, B.Sc.
Assistant Staff	... ...	N. Ellement, P. W. Tomkins, Barbara Young

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Voluntary Worker	...	S. Pradhan, M.Sc., B.Sc., D.Sc.
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Assistant Staff	... ...	S. T. Eames, Mary Gibson, Diana Jeakins, Elizabeth Reid

Field Experiments—

Head of Section	H. V. Garner, M.A., B.Sc.
	M. J. Allen
	Myrtle Hughes (Clerical Assistant)
	Kathleen J. Skidmore, N.D.D.
	J. W. Weil, M.A.
	B. Weston (Field Superintendent)

Farm Staff—

Farm Manager	J. R. Moffatt, B.Sc.(Agric.), N.D.A., A.I.B.A.E.
Assistants to Farm Manager	G. F. Cole, C. R. Scowen
Secretary	Pauline M. Cope
Experimental Assistant ...	P. G. Henden
Foreman	H. Currant
Farm Workers	T. Ablewhite, J. Bird, P. Bird, J. H. Burslem, W. Cain, H. S. Chapman, P. Hine, G. Kunath, A. Mills, F. Stokes, J. Underhill, H. A. Walford, Joyce Ward, L. Wright

Administrative and Clerical Staff—

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Director's Private Secretary	Margaret A. Bushell
Senior Assistants ...	Mrs. Olive Coleman
	Mildred Ashford
Junior Clerks	Mary Gooding, Stella Smith, Beryl Thorne
Part-time Assistant ...	Mrs. F. Doncaster
Part-time Assistant to Director's Private Secretary	Barbara J. Bushell

Library—

Librarian	Isobel M. Anderson, M.A.
Librarian's Assistant ...	Toni Sumner

Photography—

Photographer	V. Stansfield, F.R.P.S.
Part-time Draughtswoman	Barbara J. Bushell

Housekeeper ... ... Marjorie Bloomfield

Maintenance Staff—

Storekeepers	A. Oggelsby, A. H. Bowden
Engineer; Joiner; Plumber	A. E. Hall, A. W. Primett, A. E. Howell
Gardeners, Cleaners, Caretakers, etc.	L. Allen, P. English, W. S. Fisher, C. A. Gurney, G. E. Hooper, F. J. Hawkins, W. J. Smith, F. J. Stock, P. Bozier, F. Hamilton, Mrs. Bozier, Mrs. Smith, J. L. T. Binder, B. G. Burgess

Members of the Scientific Staff who left between January and December, 1947, to take up new appointments at home and overseas:

Physics Department ...	B. A. KEEN, D.Sc., F.INST.P., F.R.S.
Chemistry Department ...	P. W. ARNOLD, B.Sc.
Soil Microbiology Dept. ...	DAGNY H. OXFORD, B.A.
Crop Physiology Section	A. G. MORTON, PH.D.
Statistical Department ...	IRENE MATHISON, M.PHIL. P. ROBINSON, B.A.
Plant Pathology Dept. ...	E. M. CROOK, M.Sc., PH.D., F.R.I.C. F. J. H. MOORE, B.Sc., PH.D.
Biochemistry Department	H. LEES, B.Sc., PH.D., A.R.I.C.
Entomology Department	W. J. GUILD, B.Sc., PH.D. W. S. RICHARDS, PH.D.
Insecticides Department	ROSEMARY I. STOKER, B.Sc.(Hort.
Soil Survey of England and Wales	D. O. HUGHES, M.Sc. E. ROBERTS, M.Sc. W. G. D. WALTERS, M.Sc.

The following spent varying periods as voluntary workers at Rothamsted during 1947:

Australia : R. J. Swabey (Soil Microbiology)

China: Miss S. T. Chan (Botany), H. F. Chu, E. K. Lee (Chemistry)

Denmark: E. Hellmers (Plant Pathology)

Egypt: M. Y. Shawarbi (Chemistry), A. K. Wafa (Bee Dept.)

France: J. Grégoire (Biochemistry)

Holland: G. J. Vervelde (Physics)

India: S. N. Banerjee (Entomology), K. S. Bhargava, R. P. Chaudhuri (Plant Pathology), C. Dakshinamurti (Physics), B. C. Deb (Chemistry), B. Pradhan (Insecticides), I. M. Sahni (Statistics), O. Talibuddin (Physics)

New Zealand: R. Packard (Physics)

Portugal: A. V. Garcia (Soil Microbiology), A. S. Teixeira (Physics)

South Africa: W. J. Luttjeharms (Plant Pathology)

Sweden: G. Julen (Soil Microbiology), E. Sylven (Entomology)

British Isles: W. R. Bradford (Insecticides), J. K. Coulter (Library), I. Crockart, H. W. Dougall (Chemistry), S. J. Ellern, W. A. Hughes (Plant Pathology), H. Irvine (Chemistry), Veronica M. Osterburg (Plant Pathology and Botany), Frieda Schimmer (Mycology), L. K. Turner (Statistics), I. H. Warren (Chemistry)

Soil Survey of England and Wales

Head of Survey	A. Muir, B.Sc., Ph.D.
Soil Surveyors	E. Crompton, M.Sc.
	B. M. Dougall, M.Sc.
	W. R. Heathcote, B.Sc., N.D.A.
	D. W. King, B.Sc.
	W. A. Mitchell, B.Sc.
	D. A. O. Osmond, M.Sc., Ph.D., A.R.I.C.
	R. S. Seale, B.A.
Chemist	H. H. Le Riche, B.Sc.
Assistant Staff	D. C. M. Giddings, Doreen Saunders

Woburn Experimental Station

Director	W. G. Ogg, M.A., B.Sc., B.Sc. (Agric.), Ph.D.
Assistant Director ...	H. H. Mann, D.Sc., F.R.I.C. (Kaisar-i-Hind Gold Medal)
Chemist	T. W. Barnes, M.Sc., F.R.I.C.
Assistants for Work	G. Pearce
	W. M. Sturgess

Farm Staff—

Farm Manager	J. R. Moffatt, B.Sc. (Agric.), N.D.A., A.I.B.A.E.
Assistant...	C. F. Cole
Foreman and Stockman...	W. A. McCallum
Farm Workers	Margaret Allsopp,
	W. L. Angell,
	Clare Horn,
	Beryl Horn,
	D. A. Neale,
	A. Sibley,
	G. Tyler

Imperial College of Science and Technology

(Research Institute of Plant Physiology)

Director	F. G. Gregory, D.Sc., F.R.S.
Head of Department ...	F. J. Richards, M.Sc.
	M. Holdsworth, Ph.D.
	W. W. Schwabe, B.Sc.
	C. Mer
	H. J. Farbrother
Assistants	W. S. Biggs
	K. Sheed

The Imperial Bureau of Soil Science

Director	G. V. JACKS, M.A., B.Sc.
Consultant Director ...	W. G. OGG, M.A., B.Sc., B.Sc. (Agric.), PH.D.
Assistants	W. D. BRIND, B.Sc. MISS H. SCHERBATOFF MRS. M. K. MILNE MISS A. E. SHARP
Clerks	CYNTHIA M. HORN, RITA M. PERRY, RUTH E. TAYLOR

The Bureau is one of ten Imperial Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is *ex officio* Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Empire by providing technical information, by promoting contact between them, and by rendering any technical assistance possible when they are in this country. A quarterly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilisers and the culture of field crops throughout the world is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Empire and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly 60 years. Lawes died in 1900 and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943 when the present Director, Dr. W. G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906, Mr. J. F. Mason built the Bacteriological Laboratory; in 1907, the Goldsmiths' Company generously provided a further endowment of £10,000, the income of which—since augmented by the Company—is devoted to the investigation of the soil. In 1911, the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent. of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Imperial Soil Bureau, Staff Common Room, and Conference Room.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928, and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

A large new South Wing was completed in 1940, and the old chemical laboratories were reconstructed. These extensions and reconstructions have provided excellent accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments; in addition a fine range of pot-culture houses was built. A new laboratory has also been built and equipped for workers from the Imperial College of Science and Technology.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930–32 and equipped for electric light and power. Further additions were made in 1939–41, and the electricity supply has now been extended to these newer buildings.

From 1926 onwards, new and greatly improved methods of field experimentation were adopted on all but the classical plots, which remained essentially unchanged. In 1945 the number of plots reached 1,722, the highest in the history of Rothamsted.

The non-experimental part of the farm was re-organised in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced, and the arable acreage was increased to meet war-time conditions.

The Library is steadily growing and now contains over 30,000 volumes dealing with agriculture and related subjects. Extra accommodation has become an urgent problem. New accessions can now be housed in the main library only by removing other books to improvised store rooms which also are rapidly approaching repletion. Miss M. S. Aslin, who had been Librarian since 1919, retired in 1942, and was succeeded in 1945 by Miss I. M. Anderson, M.A. The catalogue of old books on agriculture in the possession of the Library was brought up to date and reprinted in 1940. Further additions to the collection of old books are made whenever opportunity occurs.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but the Station gains considerably by this closer association with the Universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934, the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted Estate were completed. The Rothamsted Trustees now own the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house, and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers, and from overseas sources.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually spreading out to the Empire and other countries. The Station regularly participates in work for the solution of agricultural problems of great importance to the Empire.

The Station offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Imperial Bureau of Soil Science, one of the ten Imperial Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

INTRODUCTION

By The Director

Staff

During the year there have been a good many changes in the staff. Dr. B. A. Keen, who had been Head of the Physics Department since he joined the Station in 1910 and Assistant Director since 1923, left in August 1947 to become Director of the East Africa Agriculture and Forestry Research Organisation. The Head of the Insecticides Department, Dr. F. Tattersfield, retired after being at Rothamsted for over 29 years, but he remains on a part-time basis to advise on the chemical side of the work. At the time of his retirement he received the O.B.E. Dr. Charles Potter, who had just spent a year in America as a Visiting Professor, succeeded him as head of the department in June 1947. Mr. N. W. Pirie took up his duties as head of the newly formed Biochemistry Department on returning from a year at the Worcester Foundation for Experimental Biology. Dr. and Mrs. D. J. Watson were granted a year's leave of absence and are spending the greater part of it at the Waite Institute, Adelaide. They are also visiting other stations in Australia, New Zealand and the United States. At the request of the Colonial Office, Dr. F. M. L. Sheffield was seconded for a year to the Clove Research Station, Zanzibar, to study a very serious disease affecting clove trees. Several other members of the staff left, some to go to University lectureships and others to posts overseas. Amongst the new appointments was that of Mr. J. B. Bennett, A.C.A., who was appointed Secretary in succession to the late Mr. W. Barnicot, M.B.E.

The administration of the plant nematology work at the Institute of Parasitology, Winches Farm, St. Albans, was transferred to Rothamsted from 1st October, 1947, and as soon as accommodation is ready for them the staff, under Dr. T. Goodey, F.R.S., will come to Rothamsted.

Voluntary workers

During the year there were 21 long-term voluntary workers at the Station. Many applications had to be refused for lack of bench space and at present there is a waiting list.

Visitors

The number of visitors has continued to rise since the war and, in 1947 well over 4,000 people came to Rothamsted. Most of them were in organised parties, but about 600 came privately: of these one half were from the British Isles, one third from foreign countries, and the remainder from the Dominions and Colonies. There was a substantial increase in the number of educational parties.

The distribution of the 139 parties was as follows:

Foreign Agriculturists	19
Scientific Societies	3
Farmers and Agricultural Students	35
Senior Science Classes from Schools	75
Various Clubs and Associations	7

During the month of July Rothamsted received the members of the 11th International Congress of Pure and Applied Chemistry, the Genetical Society, and the Institute of Physics.

The distinguished visitors included Mr. Henry Wallace, formerly vice-president of the United States, who came on 15th April, accompanied by the Rt. Hon. Tom Williams, Minister of Agriculture.

A few specialists are now beginning to arrive from ex-enemy countries. During the year we had visitors from Germany, Austria, Italy, Hungary and Finland.

Accommodation

During the year a certain amount of building work was carried out. The lecture room at Red Gables was enlarged and a new kitchen provided to enable mid-day meals to be served to the staff. The top floor of the Plant Pathology building has been altered and re-equipped to house the Pedology Department and Soil Survey, and a new building for the Nematology Department is nearing completion. Work has been started on a new road from the laboratories to the farm and six new farm cottages are in course of erection.

The work of the station

A considerable amount of work is in progress on the soils and crops of the Classical fields. A new series of analyses reveal no net loss of organic matter from the soils of the wheat plots on Broadbalk field since fallowing was introduced twenty years ago.

The studies on the viability of weed seeds from Broadbalk is nearing completion. Much trouble has been encountered in the past few years from wild oats, not only on Broadbalk and Hoos but on certain of the experiments at Woburn. Other work on Broadbalk includes investigations on the actinomycete flora on earthworms and on wheat midges.

A large programme has been carried out on soil fertility questions. Preliminary tests with an experimental fertiliser seed drill gave promising results with sugar beet, mangolds, swedes, and peas. One of the merits of controlled placement is that in a dry season it ensures that most of the fertiliser is in a moist state.

Field experiments on potatoes over the two contrasted seasons of 1946 and 1947 showed that broadcasting fertilisers before ridging was much less efficient than applying them after ridging and controlled placement gave no advantage over broadcasting on the prepared ridges. Field trials with sugar beet over three seasons showed that salt was equally effective when broadcast or ploughed in during the winter as when broadcast in spring.

Experiments on the manuring of forest nurseries are proving to be very interesting and already results of use in practice have been obtained, especially from the use of superphosphate and, on watered plots, from nitrogen top-dressings. Seedlings and transplants from many experiments were planted out in forests to test the effect of early treatments on forest establishment and growth.

Work on phosphates has been continued and a study has been made of the occurrence in organic soils of complexes between heavy metals and certain fractions of the organic matter. Sodium pyrophosphate proved a very convenient extractant in this work and is being used in systematic attempts to fractionate soil organic matter and to classify the various ways in which heavy metals occur in soils.

Other soil work in progress concerns the effect of micro-organisms on soil structure and it has been shown that fungal mycelium has the best effect. In association with the Road Research Laboratory a study has been made of the microbial decomposition of resins that have been prepared for use in soil stabilisation.

Other microbiological investigations are concerned with mycorrhiza, myxobacteria, and protozoa. An interesting investigation on effective and ineffective strains of nodule bacteria of clover has been continued. The work includes studies on the physiology of nodule formation, genetics of clover in relation to nodule formation, the establishment of nodule bacteria in field soil and the stability of bacterial strains. In a study of nitrifying bacteria it has been found that certain trace elements affect the oxidation of ammonia to nitrite.

The work on deep and shallow ploughing has been continued. For the third year in succession potato yields have been unaffected but significant responses have been obtained with wheat. The meteorological work has been continued and extended in relation to studies of insect flight and spore dispersal. Estimates have been made of the transpiration from extended areas of grassland. Other work in the Physics Department includes studies of the migration of ions, negative adsorption and vapour pressures of aqueous solutions. A new technique of measuring the separated diffusion of anions and cations has been developed.

On the pedological side work has been handicapped because the laboratories are under reconstruction, but some work has been done on rock weathering and on the oxidation of iron in soils. Professor Mannkopff and Mr. Albrecht from Göttingen have been spending some time at Rothamsted and giving help in the setting up of the spectrographic section.

The Botany Department continued its work on minor elements and a special study was made of molybdenum. Other work included the effect of root temperature and light on growth, and studies on the viability of buried weed seeds. Botanical separations are being made of samples from all the Park Grass hay plots, and the material accumulated since 1919 is being gradually worked up with the intention of bringing the survey up to date since the issue of "Manuring of Grassland for Hay", which dealt with all the earlier work. In Crop Physiology the main lines of work are on the physiology of leaf growth and on the effect of cultivations and fertiliser applications on the activity of roots, and the consequent effects on crop yields.

On the plant pathological side the virus studies were continued very actively, particularly on the nature of viruses and on the conditions of the host plants that affect resistance. The field work, as before, was done mainly on the potato and sugar beet crops. Biochemical studies have been made of various plant viruses and work done on the factors influencing the extraction of protein from leaves. On the mycological side, investigations on violet root rot disease, clubroot, and eyespot, were continued. It was found that the survival in soil of the fungus causing violet root rot was prolonged by increased carbohydrate and lessened by nitrogen. Soil conditions favouring infections with *Plasmodiophora brassicae* were

those in which resting spores germinate most readily in fallow soil. Next to rotation, spring rainfall had the greatest influence on the incidence of *Cercosporella herpotrichoides*, but any conditions increasing humidity within the crop increased eyespot and lodging; there was less eyespot in 1947 than in any of the previous 10 years.

In the Entomological Department the work on insect migration was continued and studies made of the relation of changes in numbers of certain common Lepidoptera to weather conditions. Much progress was made on the earthworm investigations, and it is unfortunate that Dr. Evans, who was in charge of this work, has left Rothamsted to take up an appointment elsewhere. The work on wheat midges has been continued and also the work on slugs. Other investigations include the drift of aphides in wind currents at various altitudes and the build up of a population of black aphis of beans.

The advisory work previously undertaken by the Bee Department is now handed over to the National Agricultural Advisory Service, but is located at Rothamsted, and more research is now possible. Work at present in hand includes a study of the behaviour of pollinating honeybees, the effect of anaesthetics upon foraging behaviour, and the floral sources from which bees obtain their pollen. A new line of investigation started during this year is on artificial insemination with a view to producing strains of bees for special purposes. Work has been commenced on the determination of the possible harmful effects of various herbicides on honeybees. Preliminary experiments have indicated that serious poisoning may occur if dinitro-ortho-cresol is used to destroy charlock whilst it is actually in flower.

The Insecticides Department has continued work on the stomach poison effect of a number of insecticides, and collaborative work on methods of estimation of the pyrethrins has also been continued. Several investigations on various aspects of the use of D.D.T. have been continued and extended. In addition to the chemical studies a good deal of physico-chemical and biochemical work was carried out. On the biological side the programme included a study of the relationship between body weight and resistance. This was found to vary with the poison used. Another piece of work was on the insect cuticle and in the larvae studied this was found to vary greatly in thickness and structure in different parts of the body. It appears that certain areas are likely to be much more permeable than others. A field experiment on the control of wireworms has been started in Little Hoos field in conjunction with the Entomology Department.

The Statistical Department has been rather handicapped through many changes occurring in staff, but final arrangements have been made for extending the department into a general research statistical service for agriculture. The National Agricultural Advisory Service and various research institutes are already making use of its services. Research in statistical methodology and in the design of experiments was continued and included studies of grass cutting techniques and the assessment of yields of grazed pastures.

The field and pot experiments at Woburn have been continued

and details of the work will be found in the Field Experiments reports and the report by Dr. Mann.

Although the Station is organised in departments the work is not carried out in water-tight compartments. Many of the investigations are carried out jointly between different departments. For instance, a joint piece of work on nitrification is being carried out by the departments of Soil Microbiology and Biochemistry; the departments of Chemistry and Biochemistry have been co-operating on manganese investigations, and there has been the very closest association between Biochemistry and Plant Pathology for many years. Physics and Crop Physiology have co-operated in studies of the effect of cultivation on root development. Physics and Entomology are co-operating on meteorological work, and a 100 ft. tower has been erected which has suction traps for insects and recording apparatus for temperature, humidity and run-of-the-wind. The Bee Department is engaged in investigations on D.D.T. jointly with the Insecticides Department, and these have proved of great interest. These are merely a few instances of the co-operative work which is now in progress.

DEPARTMENT OF PHYSICS

By R. K. Schofield

Shortly after his return from West Africa Dr. Keen went, at the request of the British Government, to East Africa to preside at an inter-territorial conference on agricultural problems and to advise on agricultural policy. He was appointed Director of the East African Agricultural and Forestry Research Organisation with effect from 1st August, 1947, since when Dr. Schofield has been in charge of the Physics Department.

Field work

Deep ploughing experiments

This series of experiments has continued to expand. Of the 15 experiments started on farms in 1944, 7 remained in experiment in 1947; of the 15 started in 1945, 12 remained in experiment; and 17 new experiments were started in the autumn of 1946 for the 1947 season. During 1947 arrangements have been made to start another 24 for the 1948 season; and all but one or two of the 36 fields under experiment in 1947 are expected to be under experiment in 1948.

These experiments are now situated in many counties of England and in two of Scotland, and the policy has been to ask the counties to undertake the actual responsibility for carrying out the experimental work on the fields. This Department remains responsible for the design, the choice of sites, and the working up of the results of all the experiments.

The results for the 1947 series have, in the main, followed the previous results. Thus, in spite of the opinions of many very successful growers, potato yields remain for the third year in succession unaffected by the depth of ploughing. For eight out of the nine comparable fields available this year the average yield on the 6–9 in. deep ploughing was 9·2 tons per acre, whilst it was 9·5 tons on the land ploughed to this depth and subsoiled and also on the land ploughed to 12-15 in. The corresponding figures for the average yields in the two previous years are 13·1, 13·0 and 13·1 tons per acre respectively. On the ninth field deep tillage appeared to increase the yield from between 1–4 tons per acre depending on the particular deep tillage treatment chosen for comparison, but the yields on different parts of the same plot were so variable that the precision of the experiment must be considered extremely low. The Rothamsted experiment again gave an increase of 0·7 tons per acre due to 12 in. ploughing compared to 6 in., making the average increase over the four years of the experiment 0·9 tons per acre. The result of this experiment thus continues to differ from those found elsewhere.

In 1947, as in 1946, deep ploughing either for wheat or for the previous crop may have increased yields by as much as 2–3 cwt. of grain. On one field on a very intractable silty clay it doubled the yield from 16–32 cwt. per acre compared with the normal ploughing of the farm. The soil on this field is typical of much of the silty soils of South-East England, and these lie in a region where deep ploughing is not practised at the present time. Deep ploughing

had little effect on the yield of barley, whether done in the autumn for the crop or for the previous crop, although, again at Rothamsted, it increased the yield by about 2 cwt. per acre.

In 1947 the effect of depth of ploughing and of the time of application of the mineral fertiliser to sugar beet were examined in more detail than previously. The result shows that on the clay soils deep ploughing increased the yield of sugar beet by about 2 tons per acre compared with normal ploughing if the fertiliser was applied in the spring after autumn ploughing, but it had little effect on yield if the fertiliser was put on the land before autumn ploughing. Ploughing in the fertiliser in the autumn to 6–9 in. increased the yield by about 1 ton compared with putting it in the seedbed, as is the usual practice. However, on the deep ploughed plots, ploughing in the fertiliser tended to give a lower yield than applying it in the spring, probably because the seedbed of these plots, made out of subsoil, was too poor for the beet to start well.

On fields on sands and limestones deep ploughing had little effect on yield compared with shallow. But there was a tendency, both this year and last, for ploughing in the fertiliser in the autumn to give about half a ton of extra beet compared with applying it in the spring, whatever the depth of ploughing.

These deep ploughing experiments have now shown that, at least for sugar beet, they must include investigations on the response of the crop to different distributions of mineral fertiliser in the cultivated layer of the soil.

On the effect of inter-row cultivations on the growth of potatoes

The experiment has been continued for another year in which the effect of earthing up, of the depth of setting the hoes and grubbers used between the rows, and of mulching on the growth and the yield of potatoes. This year none of the treatments had any significant effect either on yield or on the proportion of potatoes greened.

METEOROLOGICAL WORK

Evaporation and transpiration

Observations have been continued, but no further analysis of data has been made as the main requirement at present is the collection of records over a period of some years to see if the earlier generalisations are valid. From the earlier work an attempt has been made to estimate transpiration losses from extended areas of grassland when rainfall is insufficient to keep soil moisture at a level high enough to maintain maximum transpiration rates. Using "field capacity" as an identifiable and reproducible reference level it is assumed that a moisture deficit is built up as transpiration exceeds rainfall, and that up to a limiting value, symbolised by C, transpiration rates are independent of the deficit. When the deficit exceeds C inches, soil factors limit water movement to the roots, and hence transpiration rates decrease. A quantitative expression of this falling off was obtained from earlier work on evaporation from bare soil. With knowledge of the time in spring when soil was at field capacity, of the succeeding weather, and of a value of C, it has been possible to follow the change in soil moisture deficit throughout the summer and autumn. Times of the first running of field drains on Cambridge University Farm have been

successfully predicted within a few days, using values of C of about 3 in. This order of magnitude can be justified from the known rooting habit of the pasture, but further research will be needed to show how it depends on crop type, manuring, crop management, and spring weather.

The concept of soil moisture deficit, referred to above, has been presented in detail to show how it can give guidance in problems associated with soil mechanics.

Meteorological equipment

Attempts to improve equipment continue. The apparatus (referred to in the 1946 report) set up to measure dew-point continuously has not been very successful, but deficiencies in the recording instrument itself have been a contributory factor, and when certain faulty components are replaced the method will be given another test before a final verdict is reached. Apparatus has been built, and is undergoing laboratory trial, for continuous recording of transpiration so that variations during the day can be determined.

An exhaustive examination of the several rain gauges at the enclosure has revealed the sources of long standing discrepancies. These are partly due to exposure and partly due to a defective gauge glass in a new 5-in. gauge. A circular turf embankment has been built round one of our gauges, and this particular gauge will be used as the standard rain gauge in future.

During the year a standard pattern of evaporimeter has been set up to trace the source of discrepancies between open water evaporation, as measured by Meteorological Office pattern tanks, and our Rothamsted equipment.

Agricultural meteorology

A short article has been published on the nature of the physical and biological problems associated with agricultural meteorology, and some steps toward their solution have been taken in collaboration with the Entomology and Plant Pathology Departments.

With the former, a tower 105 ft. high has been set up, and the Physics Department has equipped it at two levels with continuous recorders for temperature, humidity and run-of-the-wind, with the dual purpose of providing the Entomology Department with contemporary physical data to link up with insect catches (aphides) and of supplying our own needs for more detailed knowledge of temperature, vapour pressure and wind velocity profiles in connection with evaporation and transpiration studies. Preliminary surveys indicate that the first purpose has been successfully achieved; as indicated above, no detailed analysis for the second purpose has yet been attempted.

For the Plant Pathology Department a small portable general purpose field unit has been designed and built to measure the same three weather elements in the restricted space available inside growing potato crops. The instrument is based on the very large negative temperature coefficient of electrical resistance of semi-conducting elements known as "thermistors". From the point of view of both Departments the year's work has been exploratory, and successfully so. In the light of experience gained a new instrument is being built which will be simpler to use and more

precise. Judging by visitors' interest a satisfactory instrument of this kind will meet a real need.

At the request of a joint sub-committee of the Meteorological, Entomological and Ecological Societies Dr. Penman is writing a book on the meteorological principles and methods of importance in the study of the effect of weather on biological activity.

Laboratory work

Physico-chemical studies

The review on p. 95 covers those sections of the physico-chemical studies which have been under investigation for a number of years. There remains for mention here a new investigation on the migration of ions through soil and other porous materials. This investigation has two objects. In the first place it should throw light on the factors controlling the rate of movement of nutrient ions towards the plant root. In the second place, since the migration must take place through water, these studies may throw light on the condition of the water in the minute interstices of the soil. The investigation has already brought to light an interesting effect when bentonite is added to a salt solution. The conductivity of N/10 potassium bromide solution is reduced 16 per cent. by adding 0·91 per cent. of a very fine bentonite which, under these conditions, forms a thixotropic gel, whereas the conductivity of N/40 potassium bromide is increased 3 per cent. by adding 0·57 per cent. of the same bentonite which in this case forms a deflocculated suspension devoid of rigidity. These bentonite particles are plates 10 A. thick.

These results strongly support the view that the bentonite particles in a thixotropic gel form a kind of network in which the edges of neighbouring particles are drawn towards each other.

Vapour pressure of solutions

The work on vapour pressure of solutions was first undertaken in order to supply information to the Bee Department about the relationship of the aqueous vapour pressure of honey to its water content. Some measurements were made using pure glucose and fructose and the question arose as to how the results should be set out. A study of the literature shows that no convenient method had been devised for expressing the departure of very concentrated solutions of non-electrolytes from ideal behaviour. Since there is an obvious analogy between the behaviour of water in a concentrated solution and water in moist soil, the problem has been examined in a more general way. We have hit upon a new handling of vapour pressure data, and a paper on this subject is in course of preparation.

DEPARTMENT OF CHEMISTRY

By E. M. Crowther

Several series of investigations involve related work in field, pot and laboratory experiments. A number of investigations on the manuring of sugar beet and peas, the use of various kinds of bulky organic manures and phosphate fertilisers were continued on similar lines to those described in the 1946 report and are not discussed here. A good deal of time was devoted to tests on new or local forms of fertiliser and to the design and analysis of results of experiments on soil fertility questions carried out by Ministry of Agriculture and the Colonial services. Much of the work was carried out as team work by several members of the Chemistry Department, often in collaboration with members of other Departments.

Fertiliser placement

Field experiments on potatoes in the United States have shown that fertiliser placed in bands beside the sets is more effective than the same quantity of fertiliser broadcast and worked into the soil before planting. It would not, however, be safe to apply the results of the American work directly to British practice because there are many important differences between the methods of planting potatoes in the two countries. Many of the American experiments were on cut sets planted mechanically but in Britain it is customary to broadcast fertiliser over drawn-out ridges before planting whole sets. The British method automatically ensures good "fertiliser placement" and there may be little advantage in using special machines to place the fertiliser in definite positions.

In 1945 an investigation was commenced under the aegis of a Conference of the Agricultural Research Council to test alternative methods of applying fertiliser to potatoes grown in ridges.

Fertiliser dispensing mechanisms used on commercial drills are not accurate enough for experimental work on alternative methods of applying prescribed amounts of fertiliser; the delivery rate for a given setting varies with the condition of the fertiliser and the atmospheric humidity. The National Institute of Agricultural Engineering, therefore, built a special experimental fertiliser placement machine to overcome this difficulty by using a positive displacement mechanism. Fertiliser is contained in a cylinder fitted with a rising piston which pushes the fertiliser out of the top of the cylinder where it is dispensed to tubes feeding adjustable coulters in the soil. Studies of this machine over two seasons showed that it could be relied upon to deliver a definite volume of fertiliser for a given distance travelled. Changes in the density of the fertiliser caused by alterations in atmospheric humidity did not cause sufficiently great changes in delivery rates to affect the accuracy of the field experiments.

In four preliminary experiments in Hertfordshire in 1945 there were only small differences between broadcasting a compound potato fertiliser over the ridges or placing it in contact with the seed, in a single band 2 in. below the seed or in two bands, 2 in. below and 2 in. on either side of the seed. At one centre very

deficient in phosphate there was some advantage at low rates of manuring from placing the fertiliser in contact with the seed.

During 1946 and 1947 25 experiments were carried out in some of the important potato-growing areas of Eastern England to test two methods of broadcasting—(a) on the plot before ridging (b) after ridging but before planting—against two methods of placement—(c) in contact with the sets (d) in two side bands 2 in. below and 2 in. to the side of the sets. A National Compound Fertiliser (7% N, 8% P_2O_5, 10·5% K_2O) was used at three rates, 5, 10 and 15 cwt. per acre, by each method. The mean increases calculated for the average dressing of 10 cwt. fertiliser per acre were:

		Increase in yield of potatoes, tons per acre				
		Broadcast		*Placement*		
	Experiments	Before ridging	After ridging	Contact	Side-bands	
1946	15	2·5	3·3	3·4	3·2	±0·17
1947	10	1·7	2·1	1·9	2·1	±0·15
1946 & 1947	25	2·2	2·8	2·8	2·8	±0·11

On the average of both seasons broadcasting after ridging and before planting was significantly better than broadcasting before ridging. The two methods of controlled placement by the experimental machine gave results very similar to those by broadcasting after ridging. From the response curves for increasing amounts of fertiliser the general conclusion can be drawn that 7 cwt. of compound fertiliser applied after ridging will give the same average yield as 10 cwt. of the fertiliser broadcast before ridging. Farmers who still apply their fertiliser before ridging would be well advised to follow the practice more common among specialist growers of applying fertilisers after ridging. So long as ridges are drawn there is little need for special machines to provide controlled placement; if mechanical planters working on the flat are to be used, broadcasting fertiliser before planting may be inefficient and some attachment will be needed to place fertilisers near the sets but not so close as to risk damage in dry seasons.

In 1945 and 1946 there were no checks to early development from heavy dressings of fertiliser in contact with the sets; in the long dry spell from mid-May to the end of June, 1947, 15 cwt. of fertiliser per acre in contact with the seed retarded early development at several centres, though the crops recovered after heavy rain at the end of June.

During 1947 preliminary experiments on fertiliser placement for row crops—sugar beet, mangolds, swedes and peas—were carried out with a special experimental drill built by the National Institute of Agricultural Engineering again using a top-delivery fertiliser mechanism. At a number of centres fertilisers placed in bands below the seed, either immediately below or a little to the side, gave much better yields than fertilisers broadcast. During the extremely dry season of 1947 much of the broadcast fertiliser must have remained uselessly in the top inch or so of dry soil. The experiments showed the danger of placing fertilisers with a high proportion of soluble salts close to the seeds of root crops, as e.g. by drilling fertiliser with the seed. In several experiments 4·5 cwt.

of National Compound No. 2 per acre placed in contact with the seed killed the plants, but the same amount placed to the side of the seed gave a good stand.

Sugar beet manuring and soil analysis

The standard series of manuring experiments testing N, P, K, Na and B fertilisers was carried out again in 1947 with at least one experiment in each factory area and there was also a smaller series on forms of nitrogen fertiliser.

The responses of sugar beet to superphosphate on 216 non-calcareous mineral soils and to potash on 248 mineral soils over the years 1936 to 1946 were examined in relation to the results of a number of analytical methods for soil samples taken from the experimental sites immediately before the fertilisers were applied in the standard series of experiments. The value of the analytical methods was assessed by evaluating the average profit (at 1946 prices) that would have accrued over the whole area represented by the experiments if certain centres had been selected for manuring by means of each analytical method in turn—the other centres being unmanured—and comparing this profit with what would have been obtained if the same total quantity of superphosphate or muriate of potash had been divided evenly over all the centres.

Only about one-quarter of the soils gave highly profitable responses to superphosphate. If one-quarter had been picked by the citric acid method as the most phosphate-deficient and given superphosphate at the rate of 1·0 cwt. P_2O_5 per acre the average profit over the whole series would have been equivalent to 0·62 cwt. of sugar per acre as compared with 0·39 cwt. of sugar per acre if the same total quantities of superphosphate had been spread over the whole of the centres at the rate of 0·25 cwt. P_2O_5 per acre. The immediate profit from superphosphate would have been increase by over one-half by using soil analysis.

The responses to potash were more general and there was therefore less opportunity for economy by omitting potash. If five-eighths of the centres chosen by the citric acid method had received 0·6 cwt. K_2O per acre, the average profit over the whole series would have been 1·57 cwt. sugar per acre as compared with 1·23 cwt. sugar per acre from distributing the same total amount of potash evenly over all centres.

There were only small differences in value between the principal recognised methods of analysis. It was possible from such investigations to improve analytical methods by prescribing the conditions under which they should be used and by changing the limits in accordance with other soil characters. Thus the citric acid method for phosphate may fail on very acid soils. For potash it gives better results if lower limits are used for heavy soils.

Salt for sugar beet

During 1944–6, 30 experiments were carried out on commercial farms to test different times and methods of applying agricultural salt. The results show that nothing would be lost by spreading the salt at a less busy time in winter. It is just as good to distribute the salt on firm land before the winter ploughing as to apply it

broadcast to the ploughed land either in winter or in spring. Salt should be used in such a way and at such a time as will get it well down into the soil.

Mean increase in sugar, cwt. per acre

	No. of trials	Mean of 3 and 6 cwt. salt per acre: Winter ploughed in	Winter broadcast	Spring broadcast	Mean of times: 3 cwt. salt	6 cwt. salt
1944	14	3·4	3·4	3·9	3·5	3·5
1945	9	4·6	3·9	4·3	4·1	4·5
1946	7	3·5	4·1	2·0	2·2	4·3
All years	30	3·8	3·7	3·2	3·2	3·9

NUTRITION PROBLEMS IN FOREST NURSERIES

First year seedlings of Sitka spruce and Scots pine raised in 1946 at Wareham, Dorset, on heathland soil carrying its first crop of conifer seedlings and treated with fertilisers gave good establishment and growth when tested in 1947 as transplants in several nurseries or when planted directly into three forests. The extremely dry conditions of 1947 restricted growth in many experiments and provided a good test for possible damage to seedlings from fertiliser salts; none was found. Although responses to nitrogen fertilisers were frequently poor, ammonium sulphate gave excellent results at two nurseries when used as top-dressings on watered plots; on several plots at each nursery the mean heights of Sitka spruce exceeded 3·0 in. Neither watering alone nor nitrogen fertiliser alone gave much improvement.

In several nurseries on heathland or forest sites there were very large benefits from superphosphate, which sometimes proved markedly better than basic slag or mineral phosphate. Superphosphate does not appear to have been tested previously in forest nurseries in this country, and recent demonstrations of its special value may prepare the way for a more general application in forest nurseries of methods of manuring developed in agriculture and horticulture. Seedlings or transplants grown with either composts, fertilisers or both gave no evidence in size and subsequent growth that the composts exerted any effect beyond supplying available nutrients. There have been several cases in which individual kinds of compost have been relatively deficient in one or other of the major plant nutrients. Many experiments are being made to test whether there are any long-term differences in the subsequent behaviour of the trees when planted in forests.

Several nurseries with neutral or calcareous soils gave particularly poor Sitka spruce and Scots pine seedlings in 1947. Treating the soil with either acid or formalin gave some improvement, but the treated soils failed to produce large plants. The precise cause of the failure has still to be determined, but some indication of a "lime-induced chlorosis" was obtained when it was found in 1947 that a local failure of conifers in a calcareous corner of an otherwise acid nursery was matched by a parallel failure of yellow lupins with equally good growth of both conifers and lupins in the acid parts of the nursery. It was found during 1947 that a number of established nurseries in which conifer seedlings grow badly had

high pH values as the result of lime, limestone or other basic materials used in manures for green crops, in composts or in calcareous seed covers. The characteristic failure of conifers on some of these soils was reproduced in pot experiments on Sitka spruce grown in mixtures of soil and acid-washed flint.

Spectrographic analysis

In the course of a large number of plant analyses by the Lundegardh flame spectrographic method, a series of crop samples was examined from an old liming experiment at Oaklands, St. Albans. This experiment was laid down in 1933 as a 5×5 Latin Square with increasing dressings of chalk. In 1946 the pH values ranged from 4·3 to 6·5. Samples of wheat taken on five occasions during 1946 showed that liming had very little effect on the concentration of calcium within the plant, but that liming had increased the concentration of magnesium and decreased that of manganese. Analyses of peas, beans, oats and barley grown on the same plots in 1945 led to the same conclusions. Rye grass and clover hay in 1947 had high calcium contents on the limed plots, but the increase in calcium was due to the higher proportions of clovers which are rich in calcium. The individual species, like the wheat and the other crops examined in previous years, showed very little effect of liming on the actual concentration of calcium within the plant.

Analyses on plants from cereal variety trials in Hertfordshire showed a higher concentration of manganese in the roots than in the tops of the plants, but the possibility of soil contamination renders the conclusion somewhat uncertain.

A number of Broadbalk soils have been analysed and a method developed for studying the ion-concentration of the soil solution.

The basic calcium phosphates

In a study of precipitated calcium phosphates over the range between the well-known materials dicalcium phosphate and hydroxyapatite $Ca_5OH(PO_4)_3$, there was no evidence of the formation of tricalcium phosphate $Ca_3(PO_4)_2$ as a definite compound. In a continuous series of solid solutions this particular composition merely marks the stage at which further uptake of calcium must be accompanied by the entry of OH (or F) ions. Precipitates of a composition represented by $Ca_4H(PO_4)_3$ were repeatedly encountered in the course of the work. They were shown to have an apatite-like structure but they also had X-ray diffraction lines indicating a sheet-like structure. Similar precipitates were described long ago by R. Warington, under the name "octo-phosphate" but they have rarely been mentioned in later work. It appears that "octo-phosphate" forms a continuous series of solid solutions with increasing amounts of calcium up to hydroxyapatite.

Some of the anomalies in the potentiometric titration curve of phosphoric acid and calcium hydroxide, the apparent weakness of dicalcium phosphate as an electrolyte, and discrepancies between experimental pH values and those calculated from the concentrations of calcium and phosphate and the dissociation constants of phosphoric acid, could be reconciled by the assumption that some such complex ion as $CaPO_4$ is present.

SOIL MANGANESE

Work on the various forms of manganese in soils was continued in collaboration with the Biochemistry Department with special reference to organic soils. Earlier work by Dion and Mann had shown that neutral pyrophosphate extracts of mineral soils contain mainly trivalent manganese. It was found that alkaline (pH 9·3) extracts of mineral soils and both neutral and alkaline extracts of fen soils contain divalent manganese. When mineral soils poor in organic matter and rich in the higher oxides of manganese are extracted with neutral pyrophosphate containing manganous sulphate, the added manganese reacts with the higher oxides to yield more soluble manganese (reverse dismutation). Under similar conditions fen soils retained large amounts of the added manganese in a form which within a few hours ceased to be readily exchangeable with ammonium acetate, but could be recovered by extraction with alkaline pyrophosphate solution. Manganese salts added to fen soils either alone or with ammonium acetate behaved in the same way as those added in neutral pyrophosphate solutions. In experiments on a number of salts it was found that Cd^{++}, Ni^{++}, and Cu^{++} were particularly effective in preventing the uptake of added manganese and in recovering the manganese held in other than readily exchangeable forms by fen soils. The same cations also increased the amount of manganese extracted from neutral organic soils containing little exchangeable manganese, though the high values obtained with ammonium acetate containing copper may have been due in part to a reduction of higher oxides of manganese in the presence of copper salts and organic matter.

Some fractionation of the complexes between metal and organic matter could be obtained by pretreating the soil with sodium chloride and then, in turn, with water, pyrophosphate solution and 2 per cent. sodium hydroxide. Manganese and copper retained by soils in forms not exchangeable for sodium could be recovered subsequently in the water or pyrophosphate extracts. It appeared that the manganese and copper in the water extracts remained combined with organic matter as in the soil itself.

SOIL IRON

Iron compounds appear to react with soil organic matter in two ways. The iron may enter the exchange position to form a material which may be described as a "basic ferric humate". Such iron can be extracted only by acids or salts capable of forming complex ions with iron. Iron may also react with amino and hydroxy or similar groups in soil organic matter to form a complex which can be extracted when soil, previously washed with a hydroxyacid, is saturated with sodium and then extracted with water. Iron present in organic complexes is left behind when sodium pyrophosphate extracts of soils are dialysed against running water.

SOIL ORGANIC MATTER

As soil organic matter is oxidised and degraded when treated with caustic alkali, an attempt was made to find alternative extractants less likely to alter the physiochemical properties of the organic complexes. The solubility of soil organic matter is largely determined by the nature and extent of its association with metals. The efficiency of neutral salt extractants appears to depend on the

ability of the anion to remove interfering metals either as insoluble precipitates or as soluble coordination complexes. It is well known that cations other than sodium, potassium and ammonium precipitate organic matter, and that calcium interferes with the extraction of organic matter. Neutral sodium pyrophosphate was found to be particularly effective for extracting organic matter from soils; the optimal conditions for this extraction were worked out.

An attempt was made to determine the forms in which organic nitrogen occurs in soils and, in particular, to establish whether or not the major part of soil nitrogen is present in the form of protein. Proteins as such could not be isolated from soil, but a considerable fraction of the nitrogen in soil hydrolysates was found to be present as α amino-acids. By determining the α amino-acid contents of various soil hydrolysates it has been shown that at least 30 to 40 per cent. of the total nitrogen in the soils examined was in some form of protein-like combination. There was some evidence that some of the organic nitrogen of soils occurs as amino-sugars.

Nitrogen contents of Broadbalk soils

A systematic survey of the chemical changes in the soils from the long-continued cropping and manuring experiments at Rothamsted is in progress. The following summary of changes over 80 years of almost continuous wheat growing is given for some of the principal plots in Broadbalk field. The plots were fallowed every fifth year from 1925.

Nitrogen percentages of Broadbalk soils, first 9 inches, passing 2mm. sieve

Annual Manuring	3 None	5 PK	7 NPK	2A Farmyard manure from 1885	2B Farmyard manure from 1843
1865	0·105	0·106	0·117	—	0·175
1881	0·101	0·107	0·121	—	0·184
1893	0·094	0·101	0·115	0·136	0·213
1914	0·093	0·103	0·115	0·191	0·251
1936	0·103	0·105	0·120	0·186	0·226
1945	0·105	0·106	0·123	0·194	0·236

The 1945 samples were taken from a large number of holes on each plot, the earlier ones from only a few holes often dug to considerable depth. There can be little doubt that the high value for plot 2B in 1914 was fortuitous, as the two samples concerned were highly discordant, probably through the inclusion of manure in one of the samples (0·266 and 0·236 per cent.).

Plots without farmyard manure appear to have reached substantial equilibrium within 20 years of the beginning of the experiment. The slight fall on the unmanured plot up to 1914 was made good more recently. On the plots with farmyard manure annually the nitrogen percentages rose steadily for about 50 years and then changed but slowly. It would be expected that fallowing every fifth year would check the accumulation of soil organic matter, because no organic matter is added in the fallow year either as manure or plant roots, and residues from recent applications would be rapidly oxidised. On the plots without

farmyard manure the nitrogen contents increased slightly after fallowing was introduced, probably as the result of the much better crops grown in the year immediately following the fallows.

Analytical methods

Particular attention was given to the development of rapid methods in analysing soils for readily soluble plant nutrients, the determination of fluorine in soils and of nitrates in soils and composts. A paper on a semi-micro method for determining carbon in soils was read to the Society of Public Analysts and other Analytical Chemists.

Methods for fertiliser experiments

For the guidance of agricultural workers in the colonies a memorandum was prepared describing some of the methods of field experimentation which had proved their value in recent manurial and soil fertility investigations in Britain.

DEPARTMENT OF SOIL MICROBIOLOGY

By H. G. Thornton

The following main lines of research were carried out during the year:—

A. Work dealing with the Soil Micropopulation

(1) *The effect of soil micro-organisms on soil structure*

Rapid improvement in the crumb structure of soil can be brought about by incorporating suitable organic matter containing readily decomposable substances. This effect is produced scarcely at all by relatively resistant materials such as well rotted farmyard manure or compost. Mr. R. J. Swaby has isolated a variety of micro-organisms from soil to which readily decomposable organic materials had been added and has tested the effect on soil crumb structure of these organisms in pure culture and in mixtures of pure cultures. The greatest as well as the most stable improvement in soil structure was produced by soil fungal mycelium. Actinomycete mycelium produced less stable aggregates, while a very small and temporary effect was produced by cultures of bacteria that produce gums. Mixed cultures containing fungi were usually more effective than mixtures of actinomycetes, yeasts or bacteria, but micro-organisms in some of the mixtures tested were found to antagonise each other with reduced effect on structure. Soil fungi also improved the structure better than did a soil suspension containing a great variety of micro-organisms. The soil crumbs produced by micro-organisms are short-lived, even those produced by fungi breaking down if bacteria or other organisms capable of attacking fungal cell walls are also present.

The more permanent soil crumbs found in some soils such as chernozems, rendzinas, krasnozems and terra rossas, cannot be fully explained as direct effects of micro-organisms. The more resistant humus seems to play a part here and an attempt is being made to determine which of the humate fractions are mainly responsible.

(2) *Nitrifying bacteria*

Dr. Jane Meiklejohn in a study of the bacteriology of ammonia and nitrite oxidation has devised an improved culture medium for use in nitrification studies and has investigated the effect of trace elements on the nitrifying activities of crude liquid cultures. This work, carried out with the co-operation of Dr. H. Lees of the Biochemistry Department, showed that iron markedly stimulated the production of nitrite from ammonium salts. A mixture of 10 trace elements lacking iron, copper and zinc was found to depress nitrite formation; this depression was prevented by the further addition of iron or copper but not by zinc. A proper balance of minor elements hence appears important to the nitrification process.

(3) *Micro-organisms attacking resinous substances in soil*

Mr. P. C. T. Jones concluded his researches on microbial decomposition of "Vinsol" and "Gum rosin" in compacted soil,

work undertaken on behalf of the Road Research Board, by investigating the stabilising action of various antiseptics added with the resins to the soil.

(4) *Soil actinomycetes*

Mr. F. A. Skinner commenced work here in August and is investigating the actinomycete flora of some Broadbalk plots comparing the flora of the wheat root surface with that of the main soil mass. This work is in its early stages.

(5) *Mycorrhizal associations*

Dr. Janet Mollison, who also commenced work here in August, has continued her investigation of mycorrhizal associations, particularly in clover and wheat roots. Her earlier work established that red and white clover plants growing in the field are always infected with a Phycomycete fungus that forms typical root associations of the "endomycorrhizal" type. A similar fungus has also been found in wheat roots and a survey is at present being undertaken of the relative abundance of mycorrhizal infections on wheat roots from variously manured plots of Broadbalk in samples taken at regular intervals. This is being carried out in conjunction with estimates of the content of fungal mycelium in these soils.

Experiments to test the comparative growth of clover with and without the Phycomycete and to study the conditions determining infection and emergence from the root are under way.

(6) *Myxobacteria*

The numbers of this group that attack true bacteria by means of antibiotic secretions are of special interest in connection with the competition between sections of the soil population. Knowledge as to their distribution in soils was wholly lacking until Dr. B. N. Singh made a survey of their distribution in Rothamsted plots and in soil samples from a wide area in Britain. He is now extending this survey to soils obtained from other parts of the world.

(7) *Protozoa.* (a) *Giant rhizopods*

Dr. B. N. Singh has continued the study of the life history and feeding habits of the giant Rhizopod, *Leptomyxa* Goodey, which he has found to be abundant in arable soil. Its development in soil under laboratory conditions is unaffected by reaction over a range fram pH 4·2 to 8·7 nor is its distribution in field soils related to their reaction. The organism is specific in its bacterial food requirements and was found to eat rather less than half of the 92 species of bacteria supplied to it in a test. It differs markedly in its preference for particular bacterial species both from true soil amoebae and from the amoebula stage of Acrasieae, but it resembles these in its dislike for bacteria that produce pigments other than yellow or orange and in its indifference to the gramstaining reaction of the bacteria.

A single individual Leptomyxa contains a large number of nuclei which undergo simultaneous division by an unusual form of mitosis in which the nuclear membrane and the nucleolus persist until telophase. The organism produces multinuclear cysts in a manner unique amongst protozoa but resembling the sclerotium formation in Myxomycetes. This formation of cysts is dependent

both on the cultural conditions and the species of bacteria supplied as food. Of 65 strains of bacteria edible to it only 20 led to the production of cysts in any considerable numbers.

(7) *Protozoa.* (b) *Effect of bacterial food on the life cycle of soil amoebae*

The part taken by active amoebae in consuming bacteria in the soil makes it important to understand the effect of the type of bacterial food on the growth of amoebae. Dr. B. N. Singh has found in previous work that certain species of bacteria are readily eaten while others are inedible to soil amoebae. Miss L. M. Crump has found that such amoebae can be trained to feed and multiply normally on a species of bacterium that was at first almost inedible to them. When fed on a pure bacterial culture whether originally edible or not the amoebae tend to lose the ability to form cysts.

(B) Investigation concerning the Nodule Bacteria of Clover

(1) *Stability of bacterial strains as regards effectivity*

The tendency for strains of the nocule bacteria to change their effectivity towards the clover plant in certain soils (see previous reports) is of great importance affecting the chances of improving clover growth by inoculation. Dr. J. Kleczkowska is investigating the problem of strain stability along two lines.

First, the tendency to produce ineffective mutants in soil is being investigated by using a strain known to be liable to change and growing this in a variety of soils in the hope of discovering the soil conditions producing the change, and also by growing a number of bacterial strains in a soil known to produce changes in some strains, in the hope of discovering a genetically stable strain. This investigation is still in progress.

Secondly, the known tendency for bacteriophage to induce the appearance of mutant forms of the bacteria differing from the parent strain in effectivity is being studied. Three bacterial strains originally ineffective towards clover were subjected to the action of 'phage. With one of these strains the 'phage failed to produce mutants differing in effectivity from the parent strain. In a second case effective and intermediate mutant strains appeared and retained their new characters after isolation and purification by plating and plant passage.

In the third case effective and intermediate mutants were obtained but repeated plating from single colonies always produced a mixture of isolates differing in effectivity, about 60 per cent. of them being ineffective. This result indicates that strains differ greatly in their stability as regards their effect on clover.

(2) *The ability of bacterial strains to establish themselves in the field*

Success in the commercial "inocúlation" of legume crops clearly depends first on the ability of the bacteria used as the inoculum to become established in the soil and produce an adequate number of nodules in the crop. Where inoculation is used to replace "wild" strains of nodule bacteria that are ineffective towards the crop, by an introduced effective strain, it is necessary to use for inoculation a bacterial strain able to establish itself in

competition with the wild strains already present in the soil. Miss Margaret Thomas is investigating the ability of selected effective strains of bacteria to produce nodules on clover inoculated with them under field conditions. Trials have been run at half a dozen centres. These involve the isolation of bacteria from an adequate number of nodules from inoculated and untreated plots and serological identification to determine the percentage of nodules in the treated plots that were produced by the inoculum. This work is still in progress.

(3) *Genetics of clover in relation to nodule formation*

Further work by Dr. P. S. Nutman in the inheritance of resistance to nodule formation suggests that the production of the cytoplasmic factor considered to be responsible for the maternal component in the inheritance is itself determined by the recessive resistant factor *r*. More than one simple resistant factor has been identified in material of different origin.

Grafting experiments with resistant and susceptible plants have shown that the resistance of the root system is independent of the genetic constitution of the scion.

Studies in the inheritance of the effectivity response have been continued.

(4) *The physiology of nodule production*

An examination has been made by Dr. P. S. Nutman of the influence of delayed inoculation on nodule formation. With effective strains moderate delay leads to an enhanced rate of nodulation but further delay to a reduced rate, but following delayed inoculation with ineffective strains no increase in rate is evident. This result is consistent with the theory that the early formation of effective nodules results in the secretion into the neighbouring tissues of a substance inhibitory to the formation of other nodules or of lateral roots nearby, but that ineffective nodules degenerate before this substance can be produced. Further experiments to test this hypothesis are in progress.

DEPARTMENT OF PEDOLOGY

By A. Muir

The work being done in the Pedology Department falls roughly into four sections: weathering of rocks and minerals, clay mineral studies, spectrographic analyses, and chemical investigations. In connection with the development of the spectrographic work the Department has been fortunate in obtaining the assistance of Prof. R. Mannkopff and Mr. H. Albrecht of Gottingen who are designing and building new apparatus.

The Soil Survey of England and Wales shares the Pedology laboratories and one or two members of the Soil Survey are collaborating in the clay mineral researches.

Weathering of rocks and minerals

A study of the weathering of the rocks of the Malvern Hills begun some years ago in the Chemistry Department and stopped during the war has been restarted in this department, the whole suite of rocks and soils having been resampled. The work includes not only the bulk changes in the rocks during weathering, but also the alteration in individual minerals and will relate these changes to the development of the soil profile. The soils of the Malverns are in general shallow and excessively drained, but there has been little or no glaciation and soils which are truly "in situ" can readily be found. In composition the rocks range from granite to appinite, a fairly basic rock, and masses of rock rich in biotite offer a good opportunity for weathering studies.

Clay mineral studies

Work which was started at Aberdeen on clay mineral complexes with organic liquids was continued in 1946. Facilities for X-ray work were kindly provided by Dr. C. A. Beevers at the Dewar Crystallographic Laboratory, Edinburgh, in the absence of suitable facilities in the Department. The results of this work have now appeared in the Trans. Faraday Soc.

In 1947 two X-ray sets were installed. One is a standard Metropolitan Vickers crystallographic unit. The other is a modification of an existing Shearer type gas tube. Power cameras of two sizes (90 and 57·4 mm.) have been designed and made for these two sets, which are now in operation.

A number of X-ray photographs of clays from Scottish podzols, which were taken at the Macaulay Institute for Soil Research, have been interpreted and the results have formed the substance of a communication to the Congress of the C.O.B.E.A. (Comité Belge pour l'Etude des Argiles) in May, 1947. This is in course of publication in "Verre et Silicates Industriels". The main results of this research are (a) the alteration of the micaceous minerals in the clay fraction, on passing up the profile, has been traced. Emphasis is laid on the progressive alteration of chlorite and biotite mica. (b) The effect of the presence of free sesquioxides in the B layer on the X-ray diagram has been traced. (c) Stress is laid,

in general, on the importance in soil clay work of studying the clay from a number of horizons of the profile so as to get an idea of their inter-relation.

A theory of the free energy relations in clay mineral complexes has been developed, based on Bangham's adsorption measurements on mica, and has been presented to a meeting of the British Rheologists Club.

A number of clay minerals are now being fractionated with the supercentrifuge as a preliminary to doing research on fixation of ions by pure clay minerals.

Work on the adsorption of organic liquids by montmorillonite and halloysite has been extended to nitriles and a beginning has been made in the determination of adsorption isotherms from solutions of organic liquids with montmorillonite. In the latter study acetone in cyclohexane has been used but the existing methods for the determination of acetone have not proved very satisfactory under the conditions of the experiment.

Spectrographic analysis

Since the laboratories only became available in the latter part of the year the main work has been the installation and testing of equipment which includes a large (Littrow) and a medium Hilger spectrograph with ancillary apparatus. Prof. Mannkopff has designed a spectrograph with glass optics and fully automatic. This with other equipment is under construction in the Station workshop.

Gleying in soils

With a view to elucidating the mechanism of gleying in soils the problem of the stabilisation of ferrous iron by various means is being studied.

As the first stage in this work the oxidation of iron under various conditions is being investigated. It seems to be established that the readiness with which atmospheric oxygen will oxidise ferrous iron is a function of the degree of ionisation of the ferrous compound. Dilute (0·1N) solutions of ferrous salts under weakly acid conditions have been shown to be remarkably stable to atmospheric oxidation. The rate of oxidation is increased markedly, however, if the ionisation of the ferrous salt is decreased in various ways. Work is in hand to develop a quantitative relationship between the rate of oxidation and degree of ionisation. It is intended to continue this work by studying the oxidation of ferrous-organic and inorganic complexes. It seems that previous work on ferrous-organic complexes needs repeating.

Work has been started on iron-clay systems. It is intended to investigate the oxidation-reduction characteristics of these systems.

DEPARTMENT OF BOTANY

By Winifred E. Brenchley

During the year 1947 no fresh line of investigation was opened up in the Department, but attention was concentrated on consolidating the results of the work in hand, and filling up the gaps in the information required by supplementary experiments. As in previous years, the long-term classical work on Park Grass and on the dormancy of buried weed seeds received due attention. On the physiological side the part played by minor elements in plant development and the influence of certain environmental conditions on growth provided abundant material for pot and water culture experiments.

A. Minor Elements

All over the world the part played by molybdenum in the plant economy continues to elude observers, the results being so variable even under apparently similar conditions that it is still not possible to give a definite answer, as can be done with boron.

(a) *Soil cultures*

Earlier work had shown that the relative toxicity of molybdenum to plants varies with the soil, and also that the reaction of different crops varies considerably in the same soil with similar molybdenum treatments. The growth of *flax* was greatly impeded on a manganese deficient Fen soil, and the molybdenum toxicity was masked in consequence, becoming more evident where a dressing of manganese sulphate had also been given.

In 1947 sowing was greatly delayed because of the difficulty in obtaining the soil owing to the severe winter and the flooding in the Fens. Again the characteristic habit of growth in flax appeared on the Fen soil, but where the main stems died most of the basal shoots grew vigorously, giving a short bushy plant, in striking contrast to the tall unbranched stems on the Woburn soil. Little seed was formed, though the quantity was higher where manganese was added. The development of the basal shoots delayed maturity very considerably, and when cut the plants were still green, though they were allowed to grow for six weeks after the Woburn plants had been harvested, when fully ripe with abundant seed.

An additional heavy dose of sodium molybdate was tested, giving a further reduction of crop. The seasonal effect was very marked, as the yield throughout was higher than in the previous years and the toxic effect of molybdenum was less drastic. On the sandy Woburn soil the lowest dressing of molybdate again had no poisonous effect, and the reduction of yield with greater amounts was less severe than on the Fen soil. It is hoped that at a later date the fibre will be extracted from this year's crop for comparison with that of earlier years.

Mustard showed considerable individuality in its response to molybdenum poisoning. Frequently one or two of the three plants

per pot were killed or seriously stunted, while the others were very similar in size and appearance to those in the control pots without molybdenum.

The acid Waterbeach Fen soil was the most harmful to growth, apart from any molybdenum dressing, and the manganese deficient Isleham Fen soil allowed as good development as several of the others. The addition of manganese pushed up the dry weight in this Fen soil above that of the controls in any of the others. The lowest dressing of molybdenum was ineffective in most cases, except on ordinary loam with and without peat, but increasing doses reduced growth in varying degrees according to the soil. The most serious toxicity occurred on the loams, and the Isleham Fen without added manganese, the crops being only from one-quarter to one-tenth that of the corresponding control. On the other soils as much as one-half to two-thirds of the control dry weight was achieved even with the heaviest dose of sodium molybdate.

Red Clover was sown in the same soils as the flax, and in similar small glazed pots. Two cuttings have already been made and the crop is being overwintered, so that only preliminary statements can be made as to the ultimate effect of the molybdenum dressings.

In the earlier weeks of the experiment the addition of manganese to the Isleham Fen soil again caused much improvement in growth, and mitigated the harmful effect of the higher dressings of molybdenum. In the autumn, after all the molybdenum had been applied and an extra dressing of basal fertiliser had been given a striking response was noted in the Isleham Fen soil without added manganese. Here the pots receiving the lowest dose of molybdenum were growing well, being dark green and healthy, whereas the controls were small, poor and chlorotic, those with the medium dose of molybdenum being similar to the controls, but rather greener. This development is being closely watched to see if it reflects an interaction between manganese and molybdenum.

(b) *Nutrient solutions*

Much of the work in nutrient solutions was hindered by the unusually hot summer. Two large sets of lettuce bolted prematurely and a long term experiment with red clover had to be abandoned on account of a severe infestation with red spider. The opportunity was taken of testing spray and dipping methods for the control of the pest, in collaboration with the Insecticide Department. It was found that the adults could be satisfactorily killed, but that the eggs survived the treatment and re-infection occurred.

Investigations regarding the need of certain crops for molybdenum were, however, continued and the response of the plant to the element studied under various nutrient conditions. It was found that the quantity of calcium provided had little effect on the appearance of molybdenum deficiency symptoms, though it materially altered the size and dry weight of the crop.

B. Effect of Root Temperature and Light on Growth

For some time past experiments have been carried out in water cultures to correlate the effect of high and low root temperatures on

growth in relation to full and subdued light intensity. The culture bottles are immersed in thermostatically controlled heated tanks, or in unheated tanks with a steady flow of cold water to keep the temperature as even as possible. Control plants are grown under normal conditions on the glasshouse bench, giving fluctuating root temperatures throughout growth. At first maximum and minimum temperature readings were made daily with a form of six's thermometers specially constructed for the purpose, but more recently two electrical recording thermometers, each fitted with four bulbs, have been installed, providing a much more complete record of what is really happening throughout the day and night.

As both the heated tanks and the thermometers are worked by electricity an experiment planned to take place under winter conditions had to be abandoned owing to the frequent electricity cuts.

Data have been obtained in connection with peas, buckwheat and flax, and are now being worked up for publication.

C. Vitality of Buried Weed Seeds

The soil samples taken from Broadbalk wheat field in 1945 for the estimation of buried weed seeds are now in their third year of examination, and are due to be completed on 30th September, 1948, after which it will be possible to compare the results with those of the 1940 sampling, and to get further evidence of the value of the 5-year fallowing cycle which is adopted on the field.

During the past year numerous enquiries have been received with regard to the control of wild oat, and an appeal was made in "Agriculture" for any methods that had been tried in various parts of the country and which offered any promise of success. The information thus received has been incorporated in a further article, and it is hoped that this pooling of scattered knowledge of this pernicious weed will extend. Meanwhile, long term pot experiments at Rothamsted on the dormancy of *Avena fatua* seeds in soil have been continued, and a similar experiment on *A. ludoviciana* has been set up. Seedlings of both species buried at depths down to 9 in. reached the surface and produced normal plants. The soil from each of the replicated pots was turned out into wooden trays about 3 in. deep and kept under suitable growth conditions. A few seeds of *A. fatua* which had been buried for 19 months at depths of 15 and 20 in. germinated under these conditions, and possibly others may appear later from the same boxes.

Bartsia odontites, a weed which is semi-parasitic on the roots of wheat in Broadbalk, has shown a very restricted period of germination in the buried weed seed experiments since 1925. Seedlings have only appeared in the sample pans from the end of February to the beginning of June, none at all occurring during the rest of the year. Experiments and observations are in hand to determine whether this behaviour is inherent in the nature of the seed, or whether it can be modified by varying conditions of germination, either in the field or glasshouse.

The experiments on the dormancy of *Urtica urens* seeds are still in progress and need to be carried on for some time yet before it can be decided whether all the buried seeds have germinated. It may prove necessary to make this a long term experiment in the absence of any outside information on the subject.

D. Park Grass Hay

For the first time since 1919 samples were taken from all the plots on the field, instead of only from selected plots. Complete botanical separations of many of the samples are in progress, and all the rest have been subjected to partial separation into grasses, leguminous and other plants. The material accumulated since 1919 is being gradually worked out, with the intention of bringing the survey up to date since the issue of "Manuring of Grassland for Hay", which dealt with all the earlier work.

DEPARTMENT OF CROP PHYSIOLOGY

By E. C. Humphries

Consequent upon the departure of D. J. Watson in June, for a year in Australia, his duties in connection with the Field Experiments were undertaken by H. V. Garner.

Analysis of growth and yield of field crops

Observations were made on wheat, barley, sugar beet, mangolds and potatoes during a 6-year period, including measurements of size attributes of the plant and density of the plant population (fresh weight, dry weight, plant and shoot number and leaf area per sample) at intervals during growth have been analysed and the results prepared for publication. From the estimates of Net Assimilation Rate obtained from these data, the effects of seasonal trends, year to year variation, differences between species and varieties, and the relation of Net Assimilation Rate to climatic factors were investigated (39). The variation in leaf area within and between years was also computed. Differences in Net Assimilation Rate between species and between varieties of sugar beet and potatoes were established. Variation in Net Assimilation Rate is of minor importance in determining differences in yield between years and between varieties of the same species ; these depend mainly on variation in leaf area.

An analysis was also made (40) of differences in dry matter yield of various crops produced by variation in mineral nutrition. Material from three of the Rothamsted classical field experiments, Broadbalk (wheat), Hoosfield (barley) and Barnfield (mangolds) was used. Nitrogenous fertilisers consistently increased Net Assimilation Rate. The effect of other nutrients on NAR were smaller and more variable. All treatments increased leaf area per plant but the time at which the effects occurred and the manner in which they were produced differed with different nutrients. Generally speaking the effects of varied nutrient supply were relatively greater on leaf area than on Net Assimilation Rate.

Other investigations

The foregoing investigations indicated that leaf area is one of the most important factors influencing dry matter yield and it is of importance to determine the factors that affect it. A. G. Morton investigated certain aspects of this problem and found that of the factors investigated nitrogen was the most important in determining rate of leaf production by the apical meristem of sugar beet.

The considerable amount of data relating to the potato storage experiments outlined in the report for the war years has been analysed, and the first part prepared for publication (42).

E. C. Humphries was appointed in February, 1947, to investigate root problems. The object is to see how soil treatments such as different methods of cultivation or of fertiliser application affect the activity of roots so as to produce differences in crop yield. Preliminary results have been obtained on the nutrient uptake of excised roots from plants grown under controlled conditions of nutrient supply in water culture and it is hoped to extend the method to field material.

DEPARTMENT OF STATISTICS

By F. Yates

The demand for statisticians trained and experienced in agricultural and biological work, mentioned in the 1946 Report, has continued to affect the Department. Following the loss of Mr. Kempthorne, on his appointment to an Associate Professorship in the Statistical Laboratory, Ames, Iowa, at the end of 1946, Mr. Quenouille was appointed to a Lectureship in Statistics at Aberdeen University on completion of his year's study leave at Cambridge, and Mr. Anscombe has been appointed to a Lectureship in Statistics in Cambridge University in succession to Dr. M. S. Bartlett, who was appointed to the newly created Chair of Statistics at Manchester University. Mr. Anscombe left to take up his appointment in January, 1948. In addition to these University appointments, Mrs. Mathison has been appointed Statistician to the East Africa Groundnut Scheme. Fortunately the increased recognition of statistics in the Universities is already beginning to bear fruit, and it may be confidently expected that the number of able mathematicians who become interested in biological and agricultural research statistics in the course of their university careers will increase considerably in the future.

In order to encourage more recruits to agricultural statistics, the Ministry of Agriculture and Fisheries and the Department of Agriculture for Scotland have instituted post graduate Scholarships in Agricultural Statistics, and three of these were awarded to scholars for study and training at Rothamsted during the year 1947–48.

Agricultural Research Statistical Service

Final arrangements for the setting up of a general Agricultural Research Statistical Service were completed during the year, and the following announcement was circulated by the Ministry of Agriculture and Fisheries to Research Institutions and the National Agricultural Advisory Service in December, 1947:

> On the basis of proposals made by the Agricultural Research Council and the Agricultural Improvement Council, it has been agreed between Rothamsted Experimental Station and the Ministry that the Statistical Department at Rothamsted should be expanded into a general Research Statistical Service.
>
> The Department has had long experience in dealing with statistical problems arising in design and analysis of experiments, the planning of field experiment programmes (so as to ensure the best utilisation of experimental resources), the planning and analysis of scientific surveys, and the critical analysis of large bodies of experimental material, and the new Service will in the main specialise in these classes of problem, though it will be prepared to assist in other work in so far as resources permit.
>
> It is intended that the Research Statistical Service shall give assistance to agricultural research stations, the National Agricultural Advisory Service and similar bodies in handling statistical problems beyond their resources. It is expected that

the Service will be of value both to Institutions which have their own statistical staff and to Institutions and workers who have not at present any proper statistical facilities.

It is not intended that this expansion should preclude the appointment of staff with statistical knowledge in Research Institutions where the nature and volume of the work appear to justify such a course. At the moment, however, the supply of trained and experienced statisticians is inadequate and it is hoped that the Research Statistical Service will be able to bridge the gap that at present exists as well as providing a source of trained statisticians for the future.

The use of Hollerith punched card equipment is planned to assist in the analysis of data from large-scale surveys, and to facilitate research into improved methods of analysis of material of this type.

Institutes or individuals wishing to make use of the Research Statistical Service should communicate direct with the Head of the Statistical Department, Dr. F. Yates, at Rothamsted Experimental Station, Harpenden, Herts.

It is not intended that any charges shall be made for the use of the Service by Agricultural Research Institutes or the N.A.A.S.

The setting up of this Service has already resulted in an expansion in the work of the Department. In particular the Provincial Experiments Committees of the N.A.A.S. are consulting us freely on problems arising in the design of their experiments, and Dr. Boyd has been actively engaged in making personal contact with the various Provincial Centres. The Department has also done a good deal of work for a number of research centres.

The Department has been extensively consulted by research workers from the colonies on the design of field experiments, particularly long-term experiments of fertility in tropical Africa. In this work Dr. Yates and Dr. Crowther actively collaborated.

United Nations Sub-Commission on Statistical Sampling

Dr. Yates was invited by the Foreign Office to become a member of the United Nations Sub-Commission on Statistical Sampling, which held its first session at Lake Success in September, 1947. The other members of the Commission are: Professor G. Darmois (France), Dr. W. E. Deming (U.S.A.), Professor R. A. Fisher (U.K.), Professor P. C. Mahalanobis (India). This Sub-Commission was set up largely at the request of the Food and Agriculture Organisation, with a view to the introduction of sound sampling methods in the World Census of Agriculture which is planned for 1950. The work of the Sub-Commission is also of importance in connection with the World Census of Population planned for the same year. The Sub-Commission has drawn up a report on the use of sampling with particular reference to these Censuses, which has already had considerable influence with those concerned with the planning of the Censuses. The Food and Agriculture Organisation held a conference of representatives of various countries concerned in the administration of under-developed areas in London in December, 1947, with the object of discussing the procedure of the Agricultural Census of such countries. Dr. Yates attended this conference as the representative of the United Nations.

One of the recommendations of the Sub-Commission was that a manual should be prepared, as a matter of urgency, giving instructions on the use of sampling methods in censuses and surveys, with particular reference to the projected Agricultural Census. Dr. Yates undertook to prepare a draft of this manual, and considerable progress has already been made.

In the course of his visit to the United States, Dr. Yates attended the International Statistical Conference in Washington, D.C., where he contributed a paper to the Session on the Theory of Statistical Sampling (59). He also paid visits to the Statistical Laboratory at Ames, Iowa, the Institute of Statistics at Raleigh, North Carolina, the Connecticut Agricultural Experimental Station, New Haven, and various other institutes. Two outstanding impressions gained on these visits were the wide adoption of the modern methods of experimental design developed at Rothamsted, particularly the use of lattice designs in variety trials and plant breeding work, and the great developments that have occurred in the use of sampling methods both in agricultural and other surveys.

Research in statistical methodology

Mr. Anscombe continued his work on the sampling theory of negative binomial and logarithmic distributions, which is required in the study of insect populations, etc. Two papers on this subject have been prepared for publication (43), (44).

Dr. Yates completed his investigation of problems arising in systematic sampling, that is, the taking of sampling points evenly spaced along a line, or over an area, instead of randomly located sampling points (56). This work involved a good deal of heavy computation in which a number of members of the Department gave considerable assistance. Mr. Quenouille also carried out an investigation in this field (51).

While at Cambridge, Mr. Quenouille made a study of the analysis of time series, such as arise in meteorology, agriculture and economics. He has prepared a number of papers on this subject (46), (47), (48), (49), (50). A paper on an earlier investigation arising out of a problem in bomb distribution, which he undertook shortly after he came to Rothamsted, is being published (52). He also contributed a mathematical appendix to a paper by P. C. T. Jones and J. E. Mollison on the estimation of soil bacteria (53).

Dr. Yates investigated the methods of analysis appropriate to data derived from genetical experiments involving all possible reciprocal crosses of a number of parental strains (54), and also methods of analysing two-way contingency tables in which one or both the classifications refer to characters, such as grades, having an underlying quantitative basis (55).

The problem of the estimation of the sampling errors of the mean of a number of sample determinations in stratified sampling when certain sampling units are missing has been investigated by Mr. Healy, and a note on the subject is being prepared. This problem arises in sampling for mean egg weight by trap nesting on particular days, since hens do not lay eggs on all days. Mr. Read has prepared a note on the practical aspects of this problem.

Design of experiments

No papers have been published in this field other than those which have already been prepared at the end of 1946, but various problems in experimental design have been under investigation, particularly in connection with long-term experiments and animal nutrition experiments. It is hoped that papers on these subjects will be prepared in the course of the coming year.

In addition, the need for a new text book on experimental design is becoming increasingly apparent. Descriptions of many of the more modern methods, which are now in current use, are only available in papers published in scientific journals, and reprints of many of these papers are now no longer available. It is intended to begin work on this text book as soon as the sampling manual is completed.

Sampling surveys

During 1947 field work for the Survey of Fertiliser Practice was continued in the South-Eastern Province, and was completed in the South-Western and Welsh Provinces. Duplicated reports have been issued for the following counties: South Essex, Isle of Ely, Lincolnshire (Holland), Lincolnshire (Lindsey), Warwickshire, Yorkshire (West Riding). Reports are in preparation for three counties of the Northern Province, and the analysis of the survey data for a further six counties was completed.

Arrangements have now been made by the Ministry for the publication of all the reports of this survey and revised copies of a number of reports have already been transmitted to the Stationery Office. It is hoped that in future the issue of duplicated reports will be unnecessary, their place being taken by the immediate publication of the final report.

The data provided by the Survey on the extent of combine drilling of cereals and other crops in different parts of the country were summarized and a report has been published in *Agriculture* (58).

A survey of the conditions under which milk is produced on farms was planned for 1947 by the Field Experiments Committee of the Agricultural Improvement Council, but it proved impossible to undertake any field work. It is intended, however, that a pilot survey shall be undertaken in 1948. The planning and analysis of the results of this survey will be the responsibility of this Department.

Assessment of yields of grazed pastures by grass cutting techniques

The work begun in 1945 in collaboration with the Chemistry Department and the Grassland Improvement Station on the evaluation of the yield of pastures by grazing and grass cutting was continued in 1947, samples being taken throughout the season on the Highfield grazing experiment. Statistical analyses of these experiments and of others carried out in other Provinces are being carried out by Dr. Boyd. It is intended that a report of the work shall be published shortly.

Resazurin research scheme

Work on this scheme has continued during the year under the supervision of Mr. Eddison. The analysis and report of an

experiment dealing with temperature compensation for storage prior to test was completed. The preliminary analysis of an experiment designed to determine the variability of milks from day to day and from churn to churn was also completed. A field trial of the methods evolved in the previous work has been instituted.

Entomology and Parasitology

In addition to work for the various departments of Rothamsted, Mr. Anscombe has acted as statistical advisor to the Advisory Entomologists. The scheme of observations of certain important pest insects ("Calendar insects") has been running smoothly. Some special observations were made last winter, 1946-47, to find out how many soil borings need be taken per field to obtain a reliable estimate of potato eelworm cyst infestation. Further observations, which should give all necessary information, are being taken this winter (1947-48).

An experiment carried out by the Parasitology Department, St. Albans, in 1946 on the use of D.D. against potato root eelworm was analysed, and six similar experiments carried out in 1947 are now in course of analysis.

A small co-operative experiment to see if different laboratories could get similar results in the determination of pyrethrin content of samples of pyrethrum flowers was examined and reported on. A much larger international experiment has been discussed.

National Institute for Research in Dairying

Mr. Healy has acted as statistical advisor to the National Institute for Research in Dairying. A thorough analysis of certain change-over nutrition experiments on dairy cows was carried out and points in the theory of the design and analysis of these experiments have been elucidated. Other items of work have included interpretation of milk flow curves, the development of tactile tests in rheology (which has application to cheese making) and hormonal treatment of goats.

DEPARTMENT OF PLANT PATHOLOGY

By F. C. Bawden

Viruses and virus diseases

The main lines of work described in previous reports were all continued. In the laboratory particular attention was paid to the conditions that affect the extraction of potato virus X from plants and that cause it to aggregate and inactivate (69 and 70). Extracts of *Phytolacca* species have long been known to inhibit plant viruses; the inhibitor was isolated and identified as a glycoprotein (82).

Electron microscopy showed that particles of potato virus X vary in size in a similar manner to those of tobacco mosaic virus. Some thousands of particles of tobacco mosaic virus from preparations made in different ways were measured to see whether any basic particles could be identified. Using micro-dissection methods, specimens suitable for examination in the electron microscope were made from cell contents of infected plants. These preparations showed the presence of large numbers of virus particles in X-bodies and crystalline inclusions caused by tobacco mosaic virus. The cytoplasmic inclusions produced by severe etch virus were found to contain large numbers of sub-microscopic crystals of various forms.

The effects of fertilisers and environmental conditions on the susceptibility of plants to virus infection were studied in the glasshouse. The susceptibility of bean and tobacco plants to tobacco necrosis, and of *Nicotiana glutinosa* to tobacco mosaic and tomato bushy stunt viruses, was consistently increased by placing plants in the dark before they were inoculated. Short periods in the dark produced responses similar to those found for prolonged periods of shading. Twenty-four hours in the dark usually produced the maximum response with beans, but with tobacco plants periods of up to 5 days increased susceptibility. Placing in the dark after inoculation had relatively little effect, but most often decreased susceptibility. It seems that infection occurs in two stages, the first of which is hindered by the presence of large amounts of photosynthetic products.

Interpreting the effects of fertilisers on susceptibility to viruses is complicated because of the effects of nutrition on the size of the plants. Assessing susceptibility by numbers of lesions per leaf may give different results than if numbers per unit area are considered. Also, when assessing susceptibility on the basis of virus concentration, there may be large differences depending on whether amount of virus per plant or per given volume of extract is considered. Phosphorus is much more important than nitrogen or potash in increasing susceptibility of plants to infection with tobacco mosaic virus and in increasing virus multiplication, but it is also the most effective nutrient in increasing plant size. Assessing susceptibility by numbers of lesions per leaf, phosphorus increased susceptibility

by about 5 times, but assessing it by lesions per unit area, phosphorus increased susceptibility by less than 50 per cent. Phosphorus doubled the concentration of virus in sap and increased the total virus content of plants by 10 times. In the presence of phosphorus, but not in its absence, nitrogen also increased the concentration of virus in sap and the total content of infected plants. Virus isolated from the differently treated plants did not differ in infectivity.

Fertilisers had no effect on the susceptibility of tobacco plants to potato virus Y when plants were colonised with single infective aphides.

Strains of cucumber mosaic virus obtained from different naturally-infected hosts differed, not only in host range and symptoms produced, but also in the ease with which they are transmitted by aphides, and the concentration they reach in plants. The last probably accounts for the differences found in such properties as dilution end point and thermal inactivation point. *Phaseolus vulgaris* var. Bountiful was found to be a suitable host for local lesion work with cucumber mosaic virus. During the winter it produces discrete necrotic local lesions, but during the summer it appears to be immune.

Studies on the insect relationships of pea mosaic and pea enation mosaic viruses showed the first to be a non-persistent and the second a persistent virus. A virus found causing severe damage to broad bean in the field seems to be different from any previously described in that it was transmitted by inoculation but not by aphides.

Field work on the epidemiology of sugar beet diseases was continued. The relationship between the aphis infestations of crops, trap catches of winged aphides and the prevalence of virus yellows was studied in the main beet-growing districts of eastern England. In a detailed survey of a limited area of Lincolnshire, infection varied in individual crops from 5 to 100 per cent. Rate of infection could not be correlated with any known over-wintering sources of virus or aphides, but it was increased by late sowing and thin stands of plant. The effect on the incidence of virus yellows in sugar beet stecklings sown at different dates and in different districts was studied. Healthy seed crops were produced by raising stecklings in districts removed from other sugar beet, but as a practical measure it raises difficult problems in transporting stecklings to the seed grower at planting time. To avoid these difficulties, experiments on clamping stecklings have been started. Tests of various strains of sugar beet and lines selected by the Plant Breeding Institute, Cambridge, were made in the field for any tolerance to yellows.

The comparative effects of yellows and mosaic in reducing the yield of sugar beet and mangolds infected at different dates were tested in a field experiment.

The usual field surveys and experiments on potato virus diseases and their insect vectors were made. The results are described in the review of work on potato virus diseases done in the department since 1940, which in part summarises the Research Bulletin prepared by Doncaster and Gregory (68).

Mycology

Work was continued on the violet root rot disease caused by *Helicobasidium purpureum* Pat. After completing a study of the production and growth of mycelial strands, attention was turned to the conditions influencing the survival of the fungus in the soil. The survival of colonies of *H. purpureum* on nutrient agars of different composition, buried in the soil, was first investigated. Plates of different nutrient agars were inoculated with *H. purpureum* and incubated for 2 months at 25°C.; the fungus colonies were buried in soil for 3–4 months, and then tested for viability by inoculation to carrot seedlings. Survival was prolonged by raising the carbohydrate concentration of the medium, but shortened by excess of nitrogen. The optimum nitrogen requirement for survival increased with rise in carbohydrate content of the medium. Survival of colonies was correlated with the production of firm resilient sclerotia around the centre of the colony. The depressing effect of excess nitrogen upon production of sclerotia and survival of colonies is attributed to an increased density of mycelial growth, leading to reduction of carbohydrate level below that required for maturation of viable sclerotia. The effect of various farming practices on the incidence of violet root rot on sugar beet crops was also studied.

Experiments have been carried out on survival in soil of the resting spores of *Plasmodiophora brassicae* Woron., the cause of clubroot. Under soil conditions favourable to infection, resting spores obviously germinate spontaneously in fallow soil, for tests show that the spore population falls by about 90 per cent. during the first few weeks after a spore suspension has been added to the soil. Thereafter, decline in viable spore population is slower. The spore population falls less rapidly in dry soils and alkaline soils than in wet or acid ones; thus soils unfavourable for infection seem also unfavourable for spontaneous spore germination. Some indication was obtained that many spores germinate soon after an alkaline soil is acidified. Trials have been carried out with substances likely to promote spore germination in fallow soil, such as allyl isothiocyanate, benzaldehyde, and picric acid. The life-cycle of the parasite is still imperfectly understood, and to gain more information attempts were made to prepare bacteriologically sterile spore suspensions with which to inoculate sterile plants and establish the organism in pure culture.

There was less eyespot (*Cercosporella herpotrichoides* Fron.) at Rothamsted in 1947 than at any time since research was first made in 1937. The late spring and dry summer both limited infection, and the results of field experiments contrasted strikingly with those obtained in 1946. In 1946 eyespot was prevalent on the experiment on Little Knott, straw was long and there was much lodging, but there were few weeds. Straw and grain yields were 67·4 and 27·0 cwt./acre. Spraying with sulphuric acid reduced eyespot, reduced lodging and increased yield by 1·8 cwt./acre. Increasing seed rate from 1½ to 3½ bushels/acre and of ammonium sulphate from 0 to 4 cwt./acre increased lodging, but had little effect on yield. In 1947 the eyespot was little, straw was short and there was no lodging, but there were many weeds. Straw and grain yield were 36·7 and 26·0 cwt./acre. Spraying reduced weeds greatly and increased

yield by 1·6 cwt./acre. Increasing rate of sowing from 1 to 3 bushels/acre gave increased yields only when nitrogen was applied.

From the results of experiments and surveys made during the last 10 years the effects on the incidence of eyespot of increasing the frequency of wheat and barley in the rotation were assessed quantitatively. Next to rotation spring rainfall was the most important determinant, though any factors that increase humidity within the crop favour eyespot and lodging.

Experiments were made to assess the effect of downy mildew (*Peronospora Schachtii* Fuckel.) on yield of sugar beet and to test the effects of planting date, isolation from other beets and sprays in controlling infection of stecklings.

DEPARTMENT OF BIOCHEMISTRY

By N. W. Pirie

The main work of the Department continues to be an investigation of the composition of the normal and virus infected leaf; we are not primarily concerned with the elementary composition, though this has been investigated during the year, but with the disposition of the various enzymic and structural components of the leaf and their relationship to each other and to the virus that may be present. In work of this type it is always necessary to consider the extent to which the conclusions may be invalidated by changes taking place during the mincing and extraction of the leaves. We have already described the artefacts that can be produced by fine milling, and the demethylation of the leaf pectin by its own pectase. Many leaves, especially those of the Cucurbitaceae, give alkaline extracts when the fibre residue left after expressing the sap is extracted with water. This phenomenon has been studied by M. Holden and she finds that it is due to an apparently non-enzymic reaction between pectic acid, calcium carbonate and phosphate. An understanding of the mechanism will enable us to avoid the inactivation of viruses or enzymes which would result if uncontrolled pH drifts were taking place. Although most plant viruses are not destroyed by proteases the complexes that they form with various leaf components are destroyed. M. V. Tracey has estimated the protease content of a variety of leaves and leaf extracts and finds that the activity present in the leaves normally used in virus work is small. There is no reason to think that this trace of protease has any serious effect on any of the conclusions that we have so far drawn.

The effects of fertiliser treatment and illumination on the susceptibility of plants to infection and on the multiplication of viruses in the infected leaf have been established, mainly by work in the Plant Pathology Department. Holden and Tracey have measured the effects of fertiliser treatments on the composition of tobacco plants grown under the conditions used in virus work. Supplements of nitrogen and phosphorus increased the dry matter, N and P contents of the plants. Nitrogen alone decreased the protease and increased the pectase content whereas phosphorus alone had the opposite effect. The effect of fertilisers on the composition and virus content of tobacco leaves systemically infected with tobacco mosaic virus was studied in a similar way. Under conditions of high phosphorus but without increased nitrogen, virus accounted for four-fifths of the nitrogen associated with the fibre.

In earlier work on the liberation of viruses from leaves some observations were made on the liberation of protein from the leaf residue and the conditions under which fairly complete mechanical liberation was possible were laid down. This work has now been extended by Crook and Holden to some thirty plant species. Wide variations were found in the extractability of the nitrogen in different species. These figures, which will be extended, are both of theoretical interest and of practical value for an investigation of the technical separation of leaf protein which is about to be made.

During the past few years our knowledge of the manner in which viruses are bound in the infected cell has been increased by

work on plant viruses in Rothamsted and on animal viruses in some other laboratories. Material with properties similar to those of highly purified virus preparations probably exists in the cell but it is accompanied by variable amounts of material that can be converted into purified virus but that is originally in a chemically more complex state. This phenomenon is still being studied with tobacco mosaic virus, tomato bushy stunt, and the Rothamsted strain of tobacco necrosis virus but no unequivocal evidence whether the complex is the primary or secondary form has been found Variable, but often large, amounts of virus are attached to the leaf fibre as well. This is not set free by grinding unless grinding of such an intensity that there is a probability of it bringing about chemical changes is used. The enzymes present in the crop of the snail readily bring about the liberation. An attempt is now being made to find which particular enzyme in this mixture is responsible.

The leaf contains a wide range of structural materials, protein, pectin, cellulose, and the more vaguely defined materials lignin and hemicellulose. The first two are probably not concerned in the anchoring of the bound virus. Lignin also is probably not involved because virus is liberated by enzyme mixtures that are not known to affect it. The roles of cellulose and the hemicelluloses could be disentangled if specific enzymes were available but in the absence of these, evidence can be got from simultaneous estimations of pentose, glucose, galactose and uronic acid. The estimation of these substances in the presence of one another is a matter of some difficulty. Tracey has developed a quick and convenient micro-method from the conventional uronic acid method and has made a more thorough study than had been made before of its specificity. He has also shown that it can be used for the determination of soil uronic acid.

The snail enzyme, although powerful, has defects. It is only readily available in summer and it has not proved possible to purify it; large amounts of nitrogen and carbohydrate have to be added, in the form of snail slimes, to any digest in which its action is being studied. We are investigating various fungus enzymes and get encouraging results with Botrytis and Aspergillus. Some fungus extracts contain predominantly polygalacturonase and our work has been greatly facilitated by a gift of highly purified polygalacturonase from Dr. Lineweaver in California.

Many factors influence the rate of action of these enzymes and we are studying the effects of different pretreatments of the leaf. In this we are, of course, limited by the fact that the ultimate object is knowledge of the manner in which virus is attached to the leaf so that no treatment is useful if it would destroy the virus. Removal of calcium ions from the leaf is a valuable step and so is the simultaneous dehydration and de-fatting that extraction with alcohol-ether mixtures brings about. This has the additional advantage that it gives the leaf a brittle texture that makes grinding very easy.

Although an investigation of the nature of soil organic matter and of the composition of some of the bacteria and funguses that play a part in building up this organic matter is part of the programme of the department, work on this aspect of the biochemistry of soil has not yet begun. Mann, in collaboration with the

Chemistry Department, has investigated the metal-organic-matter complexes of the soil. This work was prompted by the observation that the manganese in pyrophosphate extracts of organic soils was in the divalent form whereas earlier work with similar extracts from mineral soils had shown that the manganese was in the trivalent form. It proved impossible to decide what proportion of the divalent manganese arose from organic complexes because the pyrophosphate extracts reduced manganese in higher states of oxidation. However, neutral and alkaline organic soils retain added divalent manganese in a form not recoverable by repeated extraction with M ammonium acetate. In some cases the recovery was increased by the addition of low concentrations of Cu, Cd, Ni, or Zn salts to the ammonium acetate. These mixtures also give higher figures for the exchangeable manganese in untreated soil than extraction with ammonium acetate alone. The effect is particularly marked with copper, which appears to catalyse the reduction of the more highly oxidised manganese of the soil. The retention of added manganese is correlated in a general way with the organic matter content of the soil and all these results support the view that the manganese is associated with the soil organic matter.

In attempting to extract metal-organic complexes, three main fractions have been obtained: the first is water soluble after extraction of the soil with sodium chloride, the second is soluble in pyrophosphate, and the third in 2 per cent. sodium hydroxide. Manganese or copper, added as sulphate, during the sodium chloride extraction, was recovered in the subsequent water or pyrophosphate extracts. In the water extracts the metals were still combined with the organic matter.

The results appear to be of agricultural significance since manganese deficiency occurs typically on alkaline organic soils and copper deficiency has frequently been attributed to fixation of copper by the soil organic matter.

Lees has got more evidence for the view already put forward that copper is essential for nitrification. In soils treated with poisons for copper (such as diethyldithiocarbamate) nitrification is inhibited but activity can be largely restored by small amounts of copper sulphate. Higher concentrations of copper and low concentrations of zinc inhibit strongly; these inhibitions depend on the pH and organic matter content of the soil. Lees suggests that at neutral or alkaline pHs metal-organic complexes are formed in which the metal is not readily available to the nitrifying bacteria.

In collaboration with the Microbiology Department Lees has investigated the trace element requirements of cultures of nitrifying bacteria from Rothamsted soil. An outstanding effect is the stimulating effect of iron. Mixtures of copper and iron have no more effect than iron alone, but either removes the inhibitory effect of an unbalanced mixture of other trace elements. A proper balance of elements is more important than the absolute level of any one ion. The effect of many organic substances on nitrification in soil has been tested but none of them have had any pronounced effect under the conditions employed.

During the early part of 1947 N. W. Pirie was absent in U.S.A. and Canada, and he attended the International Cytological Congress in Stockholm in July.

DEPARTMENT OF ENTOMOLOGY

By C. B. Williams

Investigations

Dr. Williams has continued his studies of insect migration, insect populations, and of the effect of weather conditions on the activity and abundance of insects.

The work on migration has consisted chiefly in the collection of a large number of records of the occurrence of immigrant insects into England during the last few years; and particularly of the Cabbage-White Butterfly and the Silver-Y Moth, both of which have come in from abroad in very large numbers recently and have done extensive damage. Co-operation has been established with workers on the Continent and a very much wider knowledge is now obtainable of the distribution of these migrants in Europe in different years. Some evidence of mass movement was obtained for the Antler Moth, a serious pest of upland pastures, which we have suspected for many years as a possible migrant.

In the study of the structure of insect populations progress has been made in the application of statistical methods to the relative abundance of different species of insects in a mixed population, which gives a new conception of the "balance" in such conditions. Also a study has been made of the importance of competition in preventing the development of two closely related species in a single ecological community. In a paper (128) evidence is brought forward that the advantages of close relationship (e.g., species in the same genus) may outweigh the disadvantages of competition, so that small communities contain fewer genera than would be expected in a community of the same size in which the species were selected without reference to generic relationships.

Before the war considerable work was carried out on the effect of weather conditions on the activity and abundance of insects by means of regular captures in a light trap; this work was a wide study on the effect on "insects" as a whole. In the last two years the study has been resumed, with the assistance of Mr. Banerjee, to test the possibility of working with single species of insects. About twenty abundant species of Lepidoptera have been chosen for study and the results are promising. The main difficulties have been: (1) the relatively short period over which any single species appears, (2) the rapid natural rise and fall of numbers during the brood, and (3) the relatively small numbers of any one species obtained in a trap. To overcome this last difficulty the number of traps has been increased to three, but it would be better still if this could be again increased to six.

The opportunity was taken of the Presidential Address to the Association of Applied Biologists (127), to show how the past activities of the Entomological Department fit into a general scheme of research in Applied Insect Ecology; with its object the study of the causes of insect outbreaks and their prevention, rather than continual expenditure on direct control methods.

The scheme is as follows:—

FACTORS AFFECTING THE TOTAL POPULATION

The Physical Environment

*Geology and Geography

*Weather and climate

The Biological Environment

Food supply

*Parasites and Predators

*Competition

FACTORS AFFECTING THE DISTRIBUTION OF THE POPULATION

*Migration, or deliberate movement

*Drift, or accidental movement by natural causes

Accidental distribution by human agency.

Work in those sections marked * is already being carried out, and it is hoped that the scope might be extended to the other fields.

Dr. Barnes reports that owing to the part-time availability of an untrained assistant he was able to extend both the wheat blossom midges study as well as the slug investigations. He also states that his attendance at the Conference of Advisory Entomologists' meeting at Aberdeen during September was of immediate and direct use in establishing contacts and interchange of views concerning gall midge and slug problems in the field.

The progress of Dr. Barnes' investigations is as follows:—

1. The long-term study of the incidence of the wheat blossom midges on Broadbalk was successfully carried out for the twenty-first year in succession. While the numbers of *Contarinia tritici* remained high (21,094 per 500 ears compared with 29,638 in 1946) those of *Sitodiplosis mosellana* fell very considerably (599 per 500 ears compared with 3,853 in 1946). This drop is probably local and not general throughout the country. The percentage grain infestation on Broadbalk remained at 13 in the case of *C. tritici* but for *S. mosellana* it fell from 13 to 2. Since *S. mosellana* does more damage than *C. tritici* this drop is important. One may expect both species to decrease generally for the next year or two.

In 1947 the wheat blossom midges apparently responded to the abnormally hot weather at the end of May and early in June more than the wheat did. The result was that *Contarinia tritici* started emerging before the wheat plant was available for oviposition. This was observed both on Broadbalk and on a farm at Bedford. Consequently these early midges laid their eggs on a weed, Couch grass, both on Broadbalk and at Bedford.

The emergence of the midges on Broadbalk field was again studied and checked against that in the new insectary at Rothamsted Lodge. The correspondence was surprisingly high.

The study of the longevity of viable larvae in the soil showed that some *S. mosellana* gathered in July, 1939, emerged successfully during 1947; they had thus survived 8 winters in the soil. It is of more than passing interest to note that this survival in the soil has now been partly confirmed by Mr. Cohen, Advisory Entomologist in the Northern Province, and his colleagues who have found large numbers of living *S. mosellana* larvae in fields which have not been under wheat since 1945 and 1944 respectively.

2. As a direct result of the observations on the wild host plants of the wheat blossom midges, a *Stenodiplosis* gall midge was recorded

for the first time from Couch grass both at Bedford and Harpenden. Superficial examination leads one to suppose this species of midge has come from Foxtail grass. This possible change of host plant may be of importance and it has already aroused the interest of Mr. W. Cottier, Senior Entomologist, of the Plant Disease Division in New Zealand.

3. Short biological studies were made on other gall midges including *Wachtliella ericina* on ornamental Heather, *Wachtliella rosarum* and *Macrolabis luceti* on Rose, *Contarinia solani* on Woody Nightshade (in an attempt to see whether this species would live on Deadly Nightshade or Tomato) and *Therodiplosis persicae* which lives on red spider on Peach and other plants grown under glass, e.g., Raspberry at Dundee.

4. The slug investigation was largely a comparison of slug activity at Bedford compared with that in Harpenden.

5. The appearance of further volumes of *"Gall Midges of Economic Importance"* was again delayed. But the final proofing and indexing of Vols. 3 and 4 was completed in August. Publication has been held up owing to shortages of binding cloth and paper, but now publication of Vol. 3 is promised for 24th March, 1948, but there is still (January, 1948) no news of Vol. 4.

Owing to this delay Dr. Barnes shelved the completion of further volumes, but intended to complete two further volumes in the year ending 30th September, 1948.

6. Identification of gall midges sent in has been almost entirely restricted to those sent in by Advisory Entomologists and others in this country. Time, however, will soon have to be made to deal with overseas consignments which have been accumulating.

Dr. Evans reports as follows on his work with Dr. Guild on the relations between earthworms and soil fertility.

The studies on the life-cycles of the common species have been continued.

FIELD STUDIES

Annual fluctuations, the results of the three years' work, suggest that, in permanent pasture, large scale fluctuations do not occur.

In leys, after arable, there is a rapid build up of the population.

In arable, after permanent grass, there is but little decrease in population during the first year but a rapid diminution thereafter

SOIL STRUCTURE

The weight of wormcasts produced per acre per annum on pastures of varying age varied from 1–25 tons and it was calculated that from 4–36 tons of soil pass through the alimentary tracts of the total population present. The percentage pore space of a soil containing a high population of casting species is much greater than that of one containing a high population of non-casting species, i.e., 67 per cent. as against 40 per cent. The amount of coarse sand relative to silt and clay increases appreciably with depth in two old pastures and this distribution is probably the result of the long continued activity of earthworms.

EFFECTS ON SOIL FERTILITY

A large scale pot experiment showed that the presence of earthworms in numbers approximating to those found in the field gave a significant increase in yield of the test crop, mustard. As a

result of the four large scale pot experiments carried out during these investigations we have reached the conclusion that this method is not suitable and that, if the investigations are to be continued, experiments should be carried out in cylinders, at least 3 ft. in diameter, sunk into the soil and exposed to natural weather conditions. The tentative conclusion that we have reached is that earthworms are not of any great importance under arable conditions but that they are of great importance in soil uncultivated by man, i.e., permanent pasture, heaths and broad-leaved forests.

Dr. Johnson reports as follows in connection with his work on the distribution of aphididae in relation to weather conditions and field outbreaks.

A. Sampling Aphids on the bean crop

A sampling technique has been developed which enables the number of aphids, predators and parasites on the bean crop to be estimated on a satisfactory statistical basis. The method depends on selecting sample plants at random, removing all aphids from them and estimating the numbers by cliquot samples from a suspension in water. A rapid assessment of numbers, growth of populations, changes in proportions of instars, alatae, etc., can now be made and provides for the first time, with this insect on beans, a basis on which to compare infestations between plots or to study quantitatively the growth and decline of the populations themsilver. The results of last year's work are now being analysed.

B. Local Flighting

Hitherto local flighting has been studied mainly by means of nets or sticky traps which have the disadvantage of sampling relatively more insects as the wind-speed increases. Since the number of aphids in the air is itself dependent on wind-speed the use of these traps introduces an undesirable complication.

Experiments have, therefore, been made with two types of suction trap, which, by sucking a known and constant quantity of air through a vertical duct, gathers insects from known volumes of air.

Continuous records of aphids in these traps have been made throughout June-December, 1947, in two localities—one in an open field and one over a small bean patch. Identification of the aphids and analysis of their numbers in relation to times of day and weather and degree of infestation of the crop are now in progress.

C. Trapping of higher altitudes

Throughout the season trapping has been in progress at the R.D.E., Cardington, where nets have been flown almost daily from a barrage balloon cable at the following heights: 50, 250, 500, 1,000, 1,500, 2,000, 3,000, and 4,000 ft. The material gathered in these nets amounts to several thousands of aphids, which are now being identified. A quantitative analysis of numbers of aphids in relation to meteorological conditions is in progress.

D. Collection of Black Aphis for Biometrical Study

A collection of Bean Aphis from beans in different localities all over the country and black aphids from other hosts at Kew and near Rothamsted have been made. The intention was to study the limits of morphological variation of the bean aphid and its relations and to see if local differences occurred. A start has been made on the measurement of some characters but pressure of other work has put it in abeyance.

BEE DEPARTMENT

By C. G. Butler

On 1st October, 1946, the advisory work and disease diagnosis, including the examination of sample brood combs submitted under the Foul Brood Disease of Bees Order, that has in the past been carried out by members of the Bee Research Department, was taken over by the National Agricultural Advisory Service of the Ministry of Agriculture and Fisheries. This advisory work is now being continued and extended by the N.A.A.S. bee-keeping officers under the supervision of Mr. P. S. Milne, who had previously been looking after this part of the Bee Department's work. This bee-keeping unit of the N.A.A.S. is at present sited at Rothamsted alongside the Bee Department the members of which, having been released from advisory work, are now able to devote all their energies to research.

This, then, is the first report of the Bee Department in recent years in which no mention is made of advisory work carried out by members of the Department. The resignation of Mr. Milne from the Rothamsted staff and the transference of the advisory work to the N.A.A.S., together with the removal of the Bee Department to Rothamsted Lodge, have necessitated a thorough reorganisation. As a result it has been possible, almost for the first time, to plan a number of long term researches in the knowledge that the advent of an unexpected amount of advisory work will not in future be likely to upset the programme and necessitate abandonment of work that has been commenced.

Pollen collecting behaviour of honeybees

During the summer of 1947 C. R. Ribbands made observations on the behaviour of honeybees when collecting pollen and, to a lesser extent, nectar, in a specially planted garden of Shirley Poppies, Eschscholtzias and Nasturtiums, from all three of which the bees collected pollen only, and Limnanthes and Nemophila, which yielded both nectar and pollen. The bees were anaesthetised and marked in such a way that individuals could readily be recognised and their movements recorded from day to day.

It was concluded that foraging honeybees exhibit a pattern of trial and error learning of considerable complexity. They compare the ease of obtaining a load from the flowers which they happen to be working with their memory of the ease with which they have obtained loads from the same and other sources in the past, and continually choose the best of those alternative crops with which they become acquainted.

A paper describing this work in full has been prepared for publication (135).

The effect of anaesthetics upon foraging behaviour

In an investigation of methods of anaesthetising and marking bees C. R. Ribbands has found that chloroform is a very satisfactory anaesthetic for bees and does not affect either their memory or behaviour. However, pollen collecting bees that are anaesthetised with either carbon dioxide or nitrogen usually cease to collect pollen and harvest only nectar. If bees that have been collecting from a plant which yields both nectar and pollen are anaesthetised with

carbon dioxide or nitrogen they frequently return on recovery to the same plant, but henceforth collect nectar only from it. It is hoped to study the effects of these anaesthetics in detail during 1948. The results that have so far been obtained suggest that carbon dioxide produces a physiological change in the bee (possibly as suggested by V. B. Wigglesworth by reducing the rate of oxidation of acid metabolites) which is equivalent to ageing. This hypothesis is compatible with O. Mackensen's discovery that if virgin or inseminated queen bees are anaesthetised with carbon dioxide it reduces the period that elapses prior to the commencement of oviposition.

Pollen trapping

The study of the floral sources from which bees obtain their pollen has been continued by J. Simpson. In addition to daily collections of pollen, by means of a pollen trap, from a colony at Rothamsted, weekly collections were made by means of similar traps at a number of outside centres. The work of identification of the pollens collected is not yet complete but the results that have been obtained so far show several interesting features.

At Rothamsted by far the greatest yields of pollen were obtained from charlock and red clover. Between 27th May and 26th June 80 per cent. of the pollen came from charlock, while from 1st to 17th August practically nothing but red clover pollen was collected. In contrast to this scarcely any pollen was collected from white clover at any time during 1947. These features were also shown, though to a lesser degree, in the data obtained from other southern areas where trapping was carried out. On the other hand in a trap in Yorkshire a considerable amount of white clover pollen was obtained, but little red clover pollen.

Considerable quantities of pollen were also obtained in some areas from unexpected sources. In June large quantities of grass pollen were obtained in Essex, while in London at about the same time privet and chestnut were important sources of pollen.

Quantities of mixed loads containing pollen and fungal spores were collected on several occasions, which suggests that fungus was attacking the flowers from which the pollen was gathered.

The possible harmful effect of various herbicides on honeybees

Experiments designed to discover any possible effect of the recently developed selective herbicides on pollinating insects, particularly on the honeybee, were commenced by G. D. Glynne Jones in May, 1947. In preliminary laboratory experiments the two "hormone type" herbicides, M.C.P.A. (2-methyl-4-chlorophenoxyacetic acid) and D.C.P.A. (2:4 Di-chloro-phenoxy-acetic acid) were not found to act as contact poisons to the honeybee but they can act as stomach poisons. Dinitro-ortho-cresol and its sodium salt were found to be highly toxic to the honeybee both as contact and stomach poisons. DNOC and especially sodium dinitro-ortho-cresylate have been found to be repellent to the foraging honeybee. In glasshouse experiments a 1 per cent. solution of sodium dinitro-ortho-cresylate was found to be sufficiently repellent to prevent a hungry bee from feeding upon sugar syrup to which it had been added.

Preliminary field experiments have indicated that poisoning of bees may be anticipated if the DNOC compounds are used to destroy charlock whilst it is actually in flower.

Sulphonamide treatment for American Foul Brood

Work on the use of sulphonamides for the treatment of colonies infected with American Foul Brood has been continued by P. S. Milne. It would seem that these drugs are unlikely to prove to be of such value in cases of this disease as had been hoped.

Adult bee diseases

A study is being made on the distribution of Nosema and Amoeba diseases. There is evidence that the incidence of Nosema disease has increased considerably. A further survey of the distribution of Acarine disease is also being made.

Bee breeding

Thanks to the discovery by Laidlaw of a new valve in the genitalia of the queen honeybee and modification by Mackensen and Roberts of Watson's technique of instrumental insemination, it is now possible to produce inseminated queens which are as satisfactory in their behaviour as naturally mated ones. This technique has been studied in detail at Rothamsted during 1947 and is now being applied successfully. The way now appears to be open to make a determined attempt to breed improved strains of bees for such purposes as the production of honey from various crops, the pollination of specific seed crops such as red clover, wax production, etc. It is intended to expand this work as quickly and as extensively as possible. Artificial insemination of queen bees will undoubtedly prove to be a most useful tool in the solution of many problems in bee research.

The effects of weather conditions upon honeybee activity

A study has now been made of the data obtained from the colonies of bees that have been kept on balances during the last twenty years. This material is now being prepared for publication.

Other studies

Observations have also been made on the methods of communiction practised by honeybees, home-finding and orientation, colony balance, etc.

DEPARTMENT OF INSECTICIDES AND FUNGICIDES

By C. Potter

Dr. Tattersfield retired from the headship of the department in June, 1947, but fortunately was able to continue working in the department on a part-time basis. Dr. Tattersfield's outstanding contributions to the field of research on insecticides and fungicides were recognised by the award of the O.B.E. in the birthday honours list.

Dr. Potter, who had spent the previous year in the United States of America as a Visiting Research Professor of Entomology at the invitation of the Rhode Island State College and the Connecticut Agricultural Experiment Station, spent the first two and a half months of 1947 in the U.S.A., touring research stations on behalf of the Agricultural Research Council. He returned to the department at the end of March and was appointed head of the department at the beginning of June.

For convenience the work of the department may be set out under five headings:—

(1) General and chemical
(2) Chemical
(3) Physico-chemical
(4) Biochemical
(5) Biological

(1) General and chemical

Some of the newer organic insecticides have been examined. These include Velsicol 1068, Toxaphene and various samples of Hexaethyl tetraphosphate, which were primarily tested to investigate their direct contact effect. The samples of Hexaethyl tetraphosphate were examined at the request of the Agricultural Research Council and were worked on more extensively than the other two chemicals which gave rather disappointing results in preliminary trials.

Hexaethyl tetraphosphate has shown a high toxicity to the insect species under test and a small scale preliminary field test indicated that it was toxic to the active stages of the greenhouse red spider although it had little or no effect on the eggs of the mite. However, its very high toxicity to man is a factor militating against the use of this insecticide.

Some further work on the chemical and insecticidal properties of *Ryania speciosa* has been carried out. Extracts of this plant material have not shown any marked toxicity to the species of insect used, but as there is reason to believe that the toxic agents are rather specific in their effect the work is being continued. Mr. Lord has been responsible for a high proportion of this work.

Mr. Way made some preliminary trials on the stomach poison effect on the larvae of the tomato moth *Diataraxia oleracea* L. of four insecticides. He showed that the larvae of this species at the stage selected were completely unaffected by doses of Rotenone as high as 0·13 mg. per larva, thiodiphenylamine at 0·12 mg. per larva, the Triethanolamine salt of 3:5 dinitro-o-cresol at 0·044 mg. per larva and zinc fluoarsenate at 0·31 mg. per larva.

As a result of work on the factors affecting the resistance of insects to insecticides, some of which is described later, it seems that the lepidopterous larvae used (*Diataraxia oleracea* L. and *Phlogophora meticulosa* L.) the stomach poison effect of DDT> γ -BHC> lead arsenate, and DDT is more effective than the gamma isomer of benzene hexachloride as a contact poison to these larvae.

Field experiments, statistically planned. A field experiment was carried out by Mr. M. J. Way to compare the efficiency of DDT and Benzene hexachloride for the control of pests of kale.

Two main treatments were carried out : (1) Drilling insecticidal dust with the seed and (2) Spraying and dusting kale seedlings after emergence. A study was made of seed germination, the emergence of seedlings and the growth of young plants.

No flea beetle infestation occurred and pest infestation generally was negligible in the two months following treatment. An analysis of the results showed that the insecticide treatments had conferred little benefit on the crop under these conditions.

Plots in which seeds were drilled with benzene hexachloride dust showed a slightly significantly higher proportion of emergence of seedlings than the DDT and control plots.

A further field experiment on the control of wireworms in Little Hoos field was started by Dr. Evans of the Entomology Department and Dr. Potter. The effect of DDT, Benzene hexachloride, Ethylene dibromide and the soil fumigant D.D. are being studied. The chemicals have been applied but the sampling has yet to be done.

(2) Chemical

Collaborative work on the method of estimation of the pyrethrins has been continued and a number of slight variations in the mercury reduction method have been tested. Among the methods tried the use of n-hexane as a solvent instead of petroleum ether had been investigated and found to be satisfactory. The work is expected to continue with the department participating in a world collaborative scheme to compare the various methods and their modifications in use at the present time.

Mr. Lord has continued his study of DDT and 23 of its analogues and the alpha, beta, gamma and delta isomers of benzene hexachloride. Data on the toxicity of these compounds to the black chrysanthemum aphid *Macrosiphoniella sanborni* Gill. and *Oryzaephilus surinamensis* L. were obtained.

It was shown that the probit lines for the DDT analogues varied both in position and slope, those for the isomers of benzene hexachloride varied in position but not in slope. In general, neither the relative positions nor the relative slopes of the probit lines for the various substances were the same with the two species of insect.

The toxicity of the substances analogous to DDT appears to be related to molecular weight with a maximum occurring in the molecular weight range 300-450. Among the DDT analogues the slope of the probit line is apparently correlated with molecular volume as given by the parachor. It has been inferred that the variations in the slopes of the probit lines arises from differences in the interactions of the poisons with the test subject. It is also suggested that the evidence indicates that the action of DDT and benzene hexachloride have a reversible physico-chemical action rather than an irreversible chemical action.

(3) PHYSICO-CHEMICAL WORK

Effect of particle size on the toxicity of suspensions of insecticide applied to the insect. Mr. McIntosh's previous work had shown that if the adult *Tribolium castaneum* Hbst. (flour beetle) is used as a test subject and dipping or spraying is used as the method of application, the toxicity of suspensions of DDT increases with increase of the crystal size of the DDT up to about 400μ. Crystals larger than this have not been tested. It has been found that the increase in toxicity is paralleled by an increased retention of the poison on the body of the insect. It is not suggested that this is the whole or even the major cause of the increase in toxicity.

Further tests were carried out using apterous viviparous females of the aphid *Macrosiphoniella sanborni* Gill. The results were unsatisfactory because considerable variation in both the absolute and relative toxicities was encountered. However, the evidence acquired indicated that a crystal size of $60 \times 15\mu$ was the least effective.

Rotenone. Using the dipping method and the adult saw-toothed grain beetle *Oryzaephilus surinamensis* L. as a test subject it was found that a decrease in the particle size resulted in an increase of toxicity and the magnitude of the particle size effect on toxicity far exceeds that obtained with DDT, over what is, if anything, a smaller range of sizes. A difference of 400 has been obtained between equal concentrations (w/v) of two suspensions of particles of two different sizes.

The results obtained to date indicate that crystal shape as apart from size have no demonstrable effect on toxicity of rotenone.

This work is being continued particularly with a view to explaining the results so far obtained.

By employing the methods he has developed here for preparing DDT suspensions of uniform crystal size Mr. McIntosh has prepared such crystals and mixed them with dust diluents, thus giving a series of dusts containing the toxic agent in a known and uniform shape and size. A number of these dust mixtures containing DDT crystals of various sizes in two diluents have been prepared for Dr. W. A. L. David of the Agricultural Research Council's Unit of Insect Physiology, Cambridge.

Sorption of DDT by chitin. Mr Lord has continued his studies on the sorption of DDT and its analogues by chitin. It has been shown that the amount sorbed is dependent on the surface area of the chitin and that sorption by the cuticle may be peculiar to the chitin since cellulose wool and silica powder do not possess this sorptive capacity for DDT and its analogues.

The rate of sorption and the amount sorbed is approximately the same for DDT as for its analogues.

(4) BIOCHEMICAL WORK

Mr. Lord has been continuing his work on the effect of insecticides on insect respiration using respirometers of a modified Barcroft pattern. The results of the initial experiments on the effect of insecticides on metabolism and death rate have been examined. The inferences drawn from the data are as follows. Toxic concentrations of DDT and its analogues applied as dusts to adult saw-toothed grain beetle *Oryzaephilus surinamensis* L. increase the rate

of oxygen uptake. Sub-lethal concentrations have no effect. With groups of starving insects the total oxygen uptake from the time of exposure till death is the same whether or not the insect is treated with DDT or its analogues, insects treated with a lethal dose of insecticide respire more rapidly and therefore die sooner than untreated insects. The stimulus of DDT to this species is apparently quantal in nature and the magnitude is independent of the concentration of DDT in the dust applied. The stimuli resulting from the action of DDT and its analogues are approximately equal, as are the rates at which the insects die.

The effect of Benzene hexachloride on adult *Oryzaephilus surinamensis* L. has been shown to be similar to that of DDT.

The qualitative effects of some other insecticides have been observed and it has been found that Rotenone and Lethane 371 depress the oxygen consumption while 3:5 dinitro-o-cresol causes the death of the insect far more rapidly than any other poison investigated.

This work is being continued. Modifications of the apparatus for the application of the poison *in situ* are being studied.

During the course of his work on the relationship between the weight of the insect and its susceptibility, Mr. Way carried out some work on the changes that occurred with larvae of tomato moth *Diataraxia oleracea* L. poisoned with DDT. Detailed studies were made of the total loss in weight, of the change in moisture content, and the change in dry weight during DDT poisoning. Over 60 per cent. loss of water occurred between the time of poisoning and death. The dry weight decreased by 3–4 per cent. and of this only 0·5 per cent. was loss in fat content.

Thus although 4–5 days may elapse before death occurs and during this period the larva is continuously active, fat does not appear to be utilised as a source of energy. Experiments showed that an untreated but starved larva utilised its stored fats.

(5) Biological

Factors affecting the susceptibility of insects to insecticides

(a) Effect of larval body weight on resistance.

During the latter part of 1946 and early 1947 Mr. M. J. Way made a detailed study of the relationship between larval body weight and the resistance of the larvae to various insecticides.

Preliminary studies with the last instar larvae of the tomato moth *Diataraxia oleracea* L. showed that as the larvae increased in weight so its resistance to stomach poisons increased. The extent of the increase varied with the insecticide used.

With lead arsenate, using larvae of weights from 0·15 gm. to 0·55 gm., there was a constant relationship between increase of weight and increase in resistance if the weight increase was x 2 the Median lethal dose had to be multiplied by 1·3.

With DDT the problem was not so simple and there is not a straight line relationship between increase in body weight and increase in resistance. There is a greater increase in resistance per unit increase in body weight at the higher larval weights than at the lower larval weights, e.g., if the larval weight is increased from 0·15 gm. to 0·30 gm. the median lethal dose increases from 0·00075 mg. per larva to 0·0030 mg. per larva, an increase of

0·015 mg. per gram; if, however, the larval weight increases from 0·45–0·55 gm. the m.l.d. increases from 0·0175–0·0440 mg. per larva, an increase of 0·265 mg. per gram.

The gamma isomer of benzene hexachloride showed a similar relationship to DDT but the changes were not so strongly marked.

These results were obtained using a technique for studying stomach poison action in which contact action was eliminated as far as possible.

A study was then made along the same lines on the effect of body weight on contact toxicity using DDT and the gamma isomer of benzene hexachloride. The dose per larva was determined by washing the insecticide from the larvae with benzene after spraying and estimating the amounts colorimetrically.

A similar relationship between body weight and resistance was found when the insecticides were applied as contact poisons as had been found when they were applied as stomach poisons although there were some differences in degree.

An interesting aspect of this comparison was that DDT proved to be more toxic as a contact poison than as a stomach poison if the amount retained on the body (producing a given percentage kill) is compared with the amount required to be ingested to produce the same kill. This can only be said to be true of this particular set of experiments.

This study with lepidopterous larvae on the relationship between body weight and resistance has proved very important in assessing the validity and significance of estimations and comparisons of toxicity. It seems probable that for stomach poisons at least, where it is only possible to use relatively small numbers of insects, estimates must be made by measuring the three variables, dose, body weight and mortality and the results analysed by the probit plane technique. It is hoped to continue this work later on.

Another item of interest brought out in the course of this work was that with the last instar larvae of tomato moth there was a sudden fall in resistance to the gamma isomer of benzene hexachloride just prior to pupation.

(b) Cuticular structure and the penetration of insecticides.

Toward the end of April, 1947, Mr. Way was seconded to the Entomology Department, Cambridge, under the direction of Dr. V. B. Wigglesworth where he commenced to work on the penetration of insecticides through the cuticle using larvae of the tomato moth as test subjects. This work is still in progress. Developmental changes in the structure of the cuticle have been studied and, as with other insects, complex structure is apparent. The cuticle consists in general of five layers of different composition which are all already present at the beginning of the last instar but which increase in thickness and change in composition during the development of the instar. In certain areas of the body wall the cuticle is specialised and may be thin with several of the layers missing. The cuticle overlying sense organs and certain areas of the prolegs and muscle insertions are examples of these areas. It would appear that the penetration of poison could occur most readily in these areas.

The difficulty of developing a technique whereby droplets of

insecticide can be placed and confined in particular areas of cuticle resulted in the failure of many attempts to determine the rate of penetration in particular areas of the cuticle, all that can be said is that with the insect under test the penetration of DDT in certain parts of the body is very slow or does not occur at all. The head and tail regions seem more sensitive than the middle regions of the body.

(c) The effect of environment on toxicity.

Mr. McIntosh found in the course of his experiments that rotenone gave a higher kill of adult *Oryzaephilus surinamensis* L. when the insects were kept after treatment at 32° C. than at 20° C., while the reverse effect was found when DDT was used.

Dr. Pradhan has been studying the effect of changes in the environment on the toxicity of residual films of insecticide.

A study was first made of the relationship between the concentration of insecticide, the time of exposure and the mortality produced.

Various techniques were worked out to ensure continuous contact between the insect and the insecticide film.

At first when adult flour beetle *Tribolium castaneum* Hbst., which does not climb on glass surfaces were used as test subjects and DDT as insecticide, films were made on filter papers and the insects confined on the films by means of inverted whole filter funnels. When the gamma isomer of benzene hexachloride (γ–BHC) was used as insecticide there was evidence of a fumigant effect with this technique and the stems and part of the cone of the funnel was cut off so that free aeration could occur, rings of glass cut from glass tubes 4–5 cms. diam. were also used. When the larvae of the diamond back moth *Plutella maculipennis* Curt. were used as a test subjects and DDT as insecticide equal films were formed on two filter papers; then one of the papers was folded into a cone by a standard technique with the film on the inner surface of the cone, the cone was then inverted over the unfolded filter paper to form an enclosure, all surfaces of which were coated with insecticide, the insects were confined in this enclosure. The cone was kept in position by a circular iron ring. When γ–BHC was substituted for the DDT, at first the cone of filter paper was perforated to allow for aeration but this proved unsatisfactory and finally a similar arrangement was adopted to that used with DDT but bolting silk was used throughout instead of filter paper.

The variation in mortality with changes in concentration and exposure time was studied using adult *Tribolium castaneum* Hbst., larval *Plutella maculipennis* Curt. and nymphs of the black chrysanthemum aphid *Macrosiphoniella sanborni* Gill. DDT was first used and then γ–BHC. The adult *T. castaneum* proved the best test subject.

It was found that at a given temperature (80° F.), if the insects were given a short exposure time (24 hrs.) and examined immediately zero mortality was obtained at all the concentrations tested, thus producing a straight line curve parallel to the Y axis at zero mortality. At the other extreme with long exposures (36 days) 100 per cent. mortality was obtained at all the concentrations tested in cluding controls, giving a straight line curve parallel to the

Y axis at 100 per cent. mortality. Intermediate exposures (all followed by immediate examination) gave curves of various shapes, for the most part sigmoid in character. This data also shows that as the strength of the film increases the average survival period on the film goes on gradually decreasing.

Some preliminary studies of the effect on toxicity of the surface on which the insecticidal film is formed were also made using both DDT and γ–BHC. The surfaces tested were glass, paraffin wax, filter paper, bolting silk, geum leaf, marrow leaf, cabbage leaf and leaves of water lily. It was found that films on waxy surfaces such as paraffin wax and leaves of water lily and cabbage were relatively non-toxic compared with glass and leaves of geum. An extensive series of experiments were then carried out to determine the effect of temperature on mortality of insects exposed to films of insecticide using adult *Tribolium castaneum* Hbst. and larval *Plutella maculipennis* Curt. From the results of these experiments together with a survey of the literature the following generalisations were inferred:

(a) That insect resistance to poisons changes with temperature as do its other vital activities, i.e., increasing up to a critical point and then decreasing.

(b) With insecticidal films the amount of poison reaching the site of action in unit time also varies with the temperature, generally, but not always, increasing with increased activity of the insect. The locomotor activity of the insect appears to play an important part in the pick-up of the insecticide. An instance where increased activity appears to result in decreased pick-up occurred with larvae of *Plutella maculipennis* Curt. where the web spun by the larvae as they moved formed a protective layer on the surface of the film.

(c) The overall effect of temperature on the insecticidal action of films is the result of the interaction between the two preceding factors, resistance and pick-up.

Finally some investigations were made on the effect of changes in relative humidity on the mortality of insects exposed to films of insecticide. In this series adult *Tribolium castaneum* Hbst. and the larvae of *Plutella maculipennis* Curt. were again used as test subjects. The two insecticides studied were DDT and 3:5-dinitro-o-cresol (DNOC).

With the adult *T. castaneum* the toxicity of both DDT and DNOC increases with increased relative humidity. This is true both during the course of exposure and after treatment.

However, when the larvae of *Plutella maculipennis* Curt. are exposed to the film for 24 hours and then inspected at once and the mortality assessed, it was found that increased relative humidity resulted in a decreased mortality with DDT films but increased mortality with films of DNOC.

No general principles could be deduced from the latter experiments and a survey of the literature. However, it seems likely that factors that must be taken into consideration besides that of the species and instar of insect and the nature of the insecticide, are the concentration of the insecticides used, the effect of humidity being discernible at some concentrations and not at others, and the range of humidity; differences may not show unless a wide range of humidities are tested.

Partly owing to the absence of Dr. Potter and partly owing to pressure of other work, only a little data was acquired on long term fluctuation of resistance, this work was done by Mrs. Gillham. Studies on the effect of environment on insect resistance apart from those carried out by Dr. Pradhan were also held up partly for the reasons given above but chiefly owing to lack of facilities for producing a controlled environment.

Insect rearing. In connection with this proposed work on rearing insects in an environment where temperature, humidity and light are controlled, Miss R. I. Stoker carried out some preliminary experiments on the effect of these conditions on plant growth. Three different illumination units were installed in a constant temperature room and controlled by means of time switches to give 14 hours light and 10 hours darkness. Unit (1) consisted of four 80 watt daylight fluorescent tubes. Unit (2) consisted of two 80 watt daylight fluorescent tubes and one 400 watt neon tube. Unit (3) consisted of two 400 watt neon tubes. The temperature of the room was approximately 27° C., the humidity was not strictly controlled.

Turnips were used as test plants. No difference was observed in germination rate but from then on there was a steady improvement in the growth and condition of the seedlings under the neon lights as compared with the fluorescent lights. The most noticeable difference was in leaf colour and size, the neon lights producing larger leaves of a darker green colour. The plants grown under the combined lights (Unit 2) gave plants rather less vigorous than the neon lights but similar in colour and texture. There were temperature differences between the units due to the large amount of heat produced by the neon lights, but this is not thought to account for the observed differences.

Many difficulties were encountered in this work owing to lack of facilities for temperature and humidity control and to frequent failures of the electricity supply but it is very much hoped that we shall be enabled to remedy these deficiencies and carry on with the work.

A considerable amount of work was carried out on the rearing of insects. The species now in regular use as test subjects were studied in order to improve the rearing techniques and additional species which might prove useful were investigated.

The ordered progress of this work also was handicapped by lack of facilities for illumination and controlled environment.

Phaedon cochleariae *F.* (*Mustard beetle*). Miss R. I. Stoker has made a detailed study of the laboratory rearing of mustard beetle. Besides being the only beetle of agricultural importance which has so far been found suitable for laboratory rearing, it has many good qualities as an experimental animal, among which are convenient size, ease of handling, absence of disease, and a host plant that can be made available throughout the year.

Detailed studies have been made on the fecundity of the adults, the viability of the eggs and the development of the larvae, pupae and adults under various conditions of lighting in the constant temperature room. It has been found that while the insect cannot be reared throughout the year in the glasshouse with natural illumination it is possible to do this in the constant temperature

room with illumination from either neon or fluorescent lights. The evidence to date suggests that the diapause does not occur with insects reared continuously at 75° F. with illumination as previously described for 14 hours per day.

The major difficulty at present is the great variation in the fecundity of the adults. Experiments have been made to determine the factors affecting egg-laying, so far with no positive results. The work is being continued.

Myzus persicae *Sulz.* Mrs. E. M. Gillham has carried out some work to compare the rates of reproduction of this aphid under three different lighting conditions at approximately constant temperature with that occurring under greenhouse conditions where there were great variations in temperature and illumination. Considerable difficulties were again encountered due to deficiencies in the apparatus and failure of the electricity supply. In addition, the insects were difficult to handle. The general indications were that over the period during which data were collected there was no significant difference between the number of young produced under the various conditions although it was usually slightly lower under glasshouse conditions. This work is only preliminary and it is hoped to undertake more detailed work if the necessary staff is available. Stocks are kept going all the year round on cabbage and turnip.

Macrosiphoniella sanborni *Gill.* (*Black chrysanthemum aphid*). This aphid can now be reared under glasshouse conditions for most of the year but there are periods in midsummer and midwinter when it is difficult to rear in numbers. Facilities for added illumination might overcome this difficulty. It is our most useful test aphid.

Macrosiphum solanifolii *Ash.* (*Green potato aphid*). This is a most valuable aphid for test purposes because it is easily handled, it lives several days with food and is, in general, resistant.

So far, however, we have found it difficult to rear continuously in numbers in spite of its wide range of host plants. It is rather susceptible to fungus disease.

Work on this species is being continued.

Acrythosiphon onabrychia [Macrosiphum pisi] (*Pea aphid*). This insect is being reared because some evidence was obtained that its resistance varied with the host plant on which it fed. However, we do not know enough about its biology to rear it successfully. It was found in one season that cultures on broad bean remained viviparous throughout the winter in the cool glasshouse while in another season when it was reared on clover it produced oviparous females in October and remained in the egg stage throughout the winter. It is hoped to find a suitable technique for rearing this insect.

Aphis fabae *Scop.* (*Bean aphid*). Considerable difficulties are now recognised to exist in the identification of this insect. At present we rear a species obtained from nasturtiums which is continuously cultured on that host. It appears to be a distinct species, as yet unnamed, and attempts to establish it on broad bean have so far been unsuccessful although it will colonise dock.

Cultures can be maintained on nasturtiums throughout the year but during the winter months reproduction is very slow under

glasshouse conditions, and again facilities for a controlled environment, including illumination, would be a great help. The insect is a very useful general test subject.

Myzus circumflexus *Buct.* This insect can be reared throughout the year on Arum lily (Richardia) and has proved a useful supplementary test subject.

Plutella maculipennis *Curt.* (*Diamond back moth*). This insect is reared all the year round in large numbers on cabbage and turnip. There is a complete absence of seasonal rhythm. The technique of rearing has been fully studied and this is probably the most easily reared in numbers of all the mandibulate species. It is used as a test subject for most phases of our work.

Diataraxia (Polia) oleracea *L.* (*Tomato moth*). This insect is used a great deal for stomach poison studies and other work. It is reared in large numbers on dock, cabbage and turnip. It normally has a diapause but this may be broken by (a) Rearing for the latter part of larval life under fluorescent lighting for 15 hours per diem, or (b) Keeping the pupae in a refrigerator for a minimum period of two months. So far 11–12 generations have been reared from the same stock at the rate of about 6 generations a year without serious trouble.

Xanthorhoe fluctuata *L.* (*Garden carpet moth*). This moth can be reared in large numbers on cabbage and turnip throughout the year. The normal diapause can be broken by refrigerating the pupae for a minimum of two months. It has not so far been widely used because it is not an economic pest.

Mamestra brassicae *L.* (*Cabbage moth*). This has been reared in large numbers on cabbage and turnip but shows more difficulty with diapause and disease than tomato moth. However, the pupae may be refrigerated for a year at least and brought out at any time to continue the life cycle.

Agrotis segetum *Schiff* (*Turnip moth*). The rearing of this species has been abandoned owing to its susceptibility to disease.

Phlogophora meticulosa *L.* (*Angle Shade° moth*) This species can be reared in large numbers using the foliage of most low plants as food. The data are not yet complete on methods of rearing throughout the year. The diapause can be broken, but all eggs laid by moths emerging in November proved to be sterile.

Abraxas grossulariata *L.* (*Magpie moth*). Work has been started on this species but no means has as yet been found for breaking the diapause.

Porthetria dispar *L.* (*Gypsy moth*). This insect has certain advantages as an experimental subject. The male and female larvae can be separated. There has been no trouble with disease and its polyphagous habits make it suitable for studies on the effect of host plant in resistance. However, since it feeds on deciduous plants it may not be reared all the year round. It has been found that by storing the eggs in a refrigerator and bringing them out at intervals during the late spring and summer, several generations of the moth can be reared in a year.

Sphinx ligustri *L.* (*Privet Hawk moth*). This insect is reared because its large size make it a suitable insect for special studies. It has been reared on privet, lilac and ash, but all attempts made to break the diapause so far have failed.

Cerura (Dicranura) vinula *L.* (*Puss moth*). This insect has been reared on willow and poplar but it is not thought to be a useful test animal.

Odonestis (Cosmotriche) potatoria *L.* (*Drinker moth*). This has been reared in small numbers on coarse grass but does not appear to be a likely subject. An attempt to break the diapause was unsuccessful.

Artia caja *L.* (*Garden tiger moth*). This insect has been reared on dock, cabbage and other plants. An unsuccessful attempt to produce a strain without a diapause was made by rearing at a constant temperature of 75° F. Further work may be done on this species.

Athalia colibri (*Turnip sawfly*). Since no hymenopterous pest was available as a test insect, rearing work was started on this species. Little data are as yet available but breeding under fluorescent lights broke the diapause on one occasion.

Effect of herbicides on bees

Mr. G. D. Glynne-Jones was seconded from the National Advisory Service in May, 1947, to work conjointly with the Insecticides Department and the Bee Department on the effect of herbicides on bees.

Preliminary experiments with proprietary herbicides showed that, at field strength, herbicides containing Dinitro-o-cresol were highly toxic both as stomach and as contact poisons to bees. Proprietary herbicides containing 2-Methyl-4-chloro-phenoxyacetic acid (MCPA) (hormone type) showed no evidence of contact effect at field strengths but some evidence of stomach poisoning effect.

Some work was then carried out to obtain a suitable laboratory technique for quantitative studies. By means of these techniques it was ascertained that the median lethal dose (m.l.d.) of sodium-dinitro-o-cresylate as a stomach poison to bees lay between 0·0020 and 0·0025 mg. per bee. It was further found that the m.l.d.'s as a stomach poison for 2–4 dichloro-phenoxy-acetic acid (DCPA) and its sodium salt were about the same and lay between 0·002 and 0·005 mg. per bee. A stable suspension of MCPA could not be prepared, but the toxicity of the sodium salt was similar to DCPA and its sodium salt.

Experiments on the contact poison effect showed the m.l.d. of DNOC to be 0·0025 mg./sq. cm. at 30° C. and of its sodium salt to be 0·0035 mg./sq. cm. at 30° C. The conditions of the test greatly affect the toxicity. MCPA and DCPA proved non-toxic at all the concentrations tested.

Experiments made by exposing bees to residual films of DNOC and its sodium salt showed that the conditions, particularly humidity, greatly affected the results, kills varying from zero to 100 per cent. mortality were recorded.

A series of experiments were made on the attractant, or repellent properties of DNOC and its sodium and ammonium salts. The general evidence was that these substances are repellent.

The overall evidence is that DNOC and its salts when applied as weedkillers are a potential danger to bees, particularly if applied to open blossom, the "hormone" type weedkillers are safer. Further work is required, especially in the field, before any very definite statements can be made.

FIELD EXPERIMENTS ON THE ROTHAMSTED FARM

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments: D. A. Boyd, E. M. Crowther, H. V. Garner, H. H. Mann, J. R. Moffatt, D. J. Watson, J. Weil, F. Yates.

From the point of view of the field experiments 1947 was an unfavourable year. Wheat and beans were drilled under rather sticky conditions and made very slow progress. At the end of January the great frost set in and lasted till the middle of March. Although the ground was snow-covered wheat and beans suffered badly. Both the bean experiments on Stackyard field were lost, most of the wheat on Agdell field failed, and an experiment put down on Delharding to test the effect of spring mowing on winter-proud wheat was abandoned although the wheat was not actually killed. When the snow cleared the land remained very wet for some weeks. Spring cereals were not drilled till mid-April nor potatoes planted till the end of May. Growth in early summer was very rapid, however, and the heat and drought which set in in July brought on the corn unusually quickly to harvest. No rain came for potatoes which looked very vigorous in the haulm but nevertheless made a rather light crop. Sugar beet grew well but the plant population was low and irregular. The real disappointment of the year was wheat which was the worst crop for many years. Other crops though somewhat below average were reasonably good.

The number of plots handled by the Field Staff in 1947 is shown in the following table:—

	Cereals and beans	Potatoes and roots	Hay	Grazing	Total
Classical	113	72	47	—	232
Long Period Rotations, etc.	215	232	56	9	512
Annual Experiments ...	321	414	—	—	735
	649	718	103	9	1,479

The total number of plots in 1946 was 1,554.

The winter failure of the beans and wheat accounted for the loss of 128 plots, so that the actual number harvested in 1947 was 1,351.

The classical fields

Broadbalk. The field was drilled at the end of October in a rather sticky seed-bed. When the snow melted in spring Section V, which is near the drain and carried the fourth crop after fallow, was badly washed. The wheat never recovered and looked poor throughout the season, with much Slender Foxtail. In fact this part of the field was very similar to the Broadbalk of the pre-fallowing days. None of the other sections were good in 1947, straw was short and there was no lodging. Wild oats were plentiful, but a thorough hand pulling by a gang of German prisoners as soon as the oats topped the wheat made a very good job of the field.

The wild oats, always worse on the dunged plot on the North side of the field, are gradually spreading southwards and have now reached as far as plot 11.

Great Hoos wheat and fallow. The wheat was the poorest crop for many years. It was thin, straggled, and the ears were very small. The crop was very little better than the unmanured plot on Broadbalk Section V.

Hoosfield. The permanent barley plots were sown on 17th April (on only three occasions in the long history of the field had drilling been so late) and even then the crop was slow to grow away owing to drought. The plots were sprayed with "denocate" quite successfully to reduce broad-leaved weeds, but as in former years the most serious trouble was wild oats. In an attempt to check this weed the same harvesting procedure was adopted as in 1946. On those plots where the infestation was slight the oats were carefully hand-pulled and the barley was cut and harvested in the usual way. Where the oats were too thick for hand-pulling all but a small fraction of each plot was cut green and the produce disposed of, the oats on the remaining area were carefully hand-pulled and the barley allowed to ripen to give an estimate of yield.

Barnfield. Dr. Peters, of the Institute of Agricultural Parasitology, St. Albans, reported on the eelworm infestation of Barnfield as estimated from cyst counts made in soil samples taken after the crop of 1946 had been lifted. The conclusion was that the infestation had not yet reached serious proportions. It was therefore decided that cropping with mangolds and sugar beet should be continued.

The land lay very wet in spring and cultivation could not begin till mid-April. Four rows of sugar beet were again sown on each of the mangold plots. The mangolds were a poor crop. The highest yield (dung and complete fertilisers) was only 14·4 tons per acre, and the plant population was low at about 15,000 per acre. The sugar beet appeared to stand up to the long drought rather better: yields ran up to 8·2 tons where the plots were fully manured, but there were only 16,000 plants per acre. Conditions for lifting the crop were excellent. A fungus disease Phoma Betae was very prevalent on the roots of the sugar beet, particularly on the plots receiving sulphate of ammonia. The mangolds were not affected.

Park Grass. Growth started very late on the grass plots, and owing to pressure of other work the first spring dressings of nitrogen could not be applied till 15th May and the second dressings till 29th May. Nevertheless in June growth was very rapid and the crop, though in general lighter than average, was very much better than might have been expected; indeed the unmanured plots and plot 7, Minerals only, gave well above their average yields. The hay was cut on 12th June.

Agdell. Most of the wheat failed on this field. On the fallow section practically none was found after the snow melted, the adjacent side of the clover strip carried an exceedingly poor plant, but the east side of the clover section nearest Harwoods Piece

carried a reasonably good plant. This plant was left, but the whole of the fallow section and the remaining half of the clover section was drilled with spring wheat.

Long-period experiments

Four-course rotation. This experiment tests the first year and residual effects of dung, straw compost, and raw straw plus fertiliser, and also of superphosphate and rock phosphate. The cropping is potatoes, barley, ryegrass, wheat. The results of the first 13 years cropping were summarised in the Station Report for 1946.

The wheat of 1947 was the poorest crop ever grown in this experiment, the mean yield being only 8·5 cwt. per acre. There was a good plant in the autumn but the crop wintered out very badly. In particular certain plots treated with rock phosphate in previous years practically failed. The ground was too wet in the autumn to make the usual sowing of ryegrass; the seed was put in in spring, 12th April, and growth was so small at the time of cutting that very light hay yields were obtained. The potatoes started in an unusually good tilth but suffered from drought before the end of the season. Barley was an even crop but rather below average.

Six-course rotation. This experiment tests 5 levels of each of the three main nutrients, N, P, and K applied direct to every crop of the rotation sugar beet, barley, clover, wheat, potatoes, rye.

Clover was very good in this rotation, most crops were up to the average but rye was poorer than usual, the straw being about a foot below the average height. Sugar beet was a rather gappy plant and gave only 4 tons of tops per acre.

Two-course rotation. The main point under test in this rotation of sugar beet and barley is the cumulative effect of dressings of agricultural salt when applied to the same plots year after year. There are also comparisons of salt and muriate of potash.

In 1947 the barley was fairly good and as usual showed little effect either from applications of salt or from residual potash. The sugar beet was rather a thin plant, except where 5 or 7½ cwt. of salt per acre had been applied, and the crop was much below the usual level. Salt again appeared to be much more effective than muriate of potash.

Highfield grazing experiment. This experiment carried out for the Royal Agricultural Society of England to measure the manurial value of cake fed on pasture is nearing the end of its third cycle. The first-year effect of cake feeding has been measured as live-weight increase of cattle and sheep, three times on each of the three cake-treated plots, and only the figures for 1948 are required to complete the corresponding nine measurements of second-year effects.

There could hardly be a greater contrast in weather between 1946 and 1947, the first was exceptionally wet in summer and the second exceptionally dry, nevertheless the gains made on the plots during the grazing season were similar.

The unmanured plot No. 9 in block III is comparable for the two years in question and gives the following figures:—

	1946	1947
Live-weight increase lb. per acre		
Cattle	278	319
Sheep	66	38
Total	344	357
Starch equivalent lb. per acre		
Cattle	1,254	1,409
Sheep	712	383
Total	1,966	1,792
Grazing days per acre		
Cattle	108	123
Sheep	309	180
Grazing period		
Cattle	May 9–Oct. 31	May 15–Sept. 18
Sheep	June 5–Nov. 28	June 11–Nov. 25

In the wet year the grass carried a higher sheep-stock and carried the cattle longer in autumn, but the starch equivalent and live-weight increase were similar in the two years, as they are largely determined by the amount of herbage produced early in the season.

The mean yields of starch equivalent and the mean live-weight increases over two seasons following the feeding of cake and the application of the conventional fertiliser equivalent of the cake averaged over the eight years of the experiment were as follows:—

	Starch equivalent cwt. per acre	Live-weight increase cwt. per acre
No cake or fertilisers ...	14·1	2·6
Fertilisers	15·4	2·7
Cake feeding	15·5	2·9

Deep-cultivation rotation experiment. This experiment, begun in 1944, consists of 6 blocks cropped with sugar beet, barley, seeds, wheat, potatoes, oats respectively, with the crops rotating on the blocks in the above order. In each block there are 16 plots testing all combinations of the following pairs of factors: 7 v. 14 inch ploughing, 0 v. dung, 0 v. superphosphate, 0 v. muriate of potash.

Deep ploughing is given for sugar beet, wheat, and potatoes. Dung is given to sugar beet (10 tons) and potatoes (20 tons), and these crops also receive the phosphate and potash treatments. The contrasted ploughings are given for the sugar beet, wheat and potato crops. All dung is applied before these ploughings, but the phosphate and potash are ploughed down on half of the plots and applied on the surface or in the drills on the other half.

In 1947 deep ploughing gave somewhat better yields of potatoes on plots receiving potash in the drills. Deep ploughing gave spectacular improvements in the sugar beet, the average increase on deep-ploughed over shallow-ploughed plots being 3·2 tons washed roots, 1·7 tons tops and 12·4 cwt. sugar per acre. This

gain from deep ploughing was attributed largely to the fact that the deep-ploughed plots were clean early in the season when the shallow-ploughed ones carried a very heavy crop of annual weeds. After weeding and singling the plants on the deep-ploughed land showed much more vigorous growth, the difference persisting throughout June and July.

THE ANNUAL EXPERIMENTS

1. *Potatoes. Organic manures.* An experiment testing eleven different kinds of bulky organic manures, each at two levels and in the presence and absence of the three standard fertilisers has been conducted each year from 1940 to 1946 in three 5×5 lattice squares with each main plot divided into quarters making 300 sub-plots. In 1947 a similar experiment was carried out on 150 sub-plots, the phosphate test being omitted. Nine farmyard manures of known history and composition, a bracken compost and raw straw were tested. Single dressings of all farmyard manures gave increases between 10 and 30 cwt. per acre. The double dressings of the well-rotted manures showed further increases but the double dressings of the fresh strawy manures gave poorer results than the single dressings. The bad effect of incorporating dry bulky material in the ridges in a dry summer was seen in an aggravated form with raw straw which at the double rate seriously reduced the crop even where sulphate of ammonia was applied with the straw.

2. *Potatoes. Time of planting. Fertilisers.* This annual experiment has with minor modifications been conducted since 1945, its primary purpose being to provide the Plant Pathology Department with material for the field study of the spread of virus diseases. Normally the experiment tests dung, nitrogen, phosphate and potash in relation to four times of planting. In 1947 owing to the late season the planting times were reduced to two, and the phosphate comparison was omitted. There was no early planting in the ordinary sense of the word, the first possible date was 5th May and the late planting was carried out on 27th May. Farmyard manure behaved very differently according to the time of planting of the tubers. On the "early" planting dung was quite effective, giving an increase of 2·46 tons of potatoes in the absence of potash; on the later-planted potatoes dung had practically no effect: it increased the yield, even in the absence of potash, only by 0·7 tons per acre.

3. *Potatoes. Cultivation experiment.* The factors tested in this experiment were earthing-up, depth of inter-row cultivation, and the application of a straw mulch between the rows. In addition, the fertiliser was either broadcast before drawing the drills or applied in the ridges before planting. With yields in the neighbourhood of 8 tons per acre none of the treatments showed marked or consistent effects.

4. *Potatoes. Residual values of applications of organic manures over seven seasons.* This experiment on dung, town refuse, fermented town refuse and screened dust began in 1940 and until 1947 carried crops of sugar beet, mangolds, barley, beans, wheat and sugar beet. Over this period the bulky manures applied amounted

to 56 tons per acre. The plots also tested the effects of muriate of potash and sulphate of ammonia applied annually. In 1947 no organic manures were given and potatoes were grown to test the residual effects. The residues from dung increased the crop by 2·2 tons per acre, those from screened dust by 0·9 tons per acre, and those from composted town refuse by 0·5 tons per acre.

5. *Potatoes. Fertiliser placement.* This experiment formed one of a series of ten. Growth was seriously checked by placing the fertiliser in a band in direct contact with the sets. The best yields were obtained from side-band placement, though on the average of all ten experiments this method had little advantage over broadcasting after ridging.

6. *Sugar beet. Fertiliser placement.* Placing fertilisers 2 in. below the seed and at either 0, 1 or 3 in. to the side gave better yields than broadcasting the fertilisers. In seven parallel experiments elsewhere different results were obtained, localised placement often being inferior to broadcasting.

7. *Wheat. Residuals from bulky organic manures applied to potatoes in* 1946. A good crop of Bersee wheat showed no residual effects from farmyard manures applied to potatoes in 1946 at rates of about 8 and 16 tons per acre.

8. *Wheat. Eyespot experiment.* The effects of rate and depth of sowing, nitrogen and spraying with sulphuric acid on eyespot, lodging and yield of wheat were tested for the second year. The late dry season (contrasting with 1946) resulted in exceptionally low eyespot incidence and very short straw; there was no lodging but weeds were unusually prevalent. Spraying reduced eyespot and greatly reduced weeds; it increased yield by 1·6 cwt. per acre. Increased rates of sowing from 1 to 2 and 3 bushels per acre increased yields only where nitrogen was applied. Both 2 and 4 cwt. sulphate of ammonia gave increased yields.

9. *Spring-sown cereals.* The yields and fertiliser responses of four spring-sown cereals were tested for the first time in 1947. Atle wheat, Plumage Archer barley, Star oats and Bersee autumn wheat were all sown on 12th April and received test dressings of 0, 0·3, 0·6, 0·9 cwt. N per acre as sulphate of ammonia, and 0 and 0·6 cwt. P_2O_5 per acre as superphosphate, 0 and 0·6 cwt. K_2O per acre as muriate of potash. All crops grew very well and responded well to nitrogen. The wheats and oats stood up at harvest but part of the barley was lodged. The responses to the heaviest dressings of nitrogen were: oats 9·4 cwt., Atle wheat 5·4 cwt., Bersee wheat 5·2 cwt. and barley 3·7 cwt. per acre. The barley showed a good response to potash and the oats to phosphate.

10. *Three-course rotation experiment on the use of straw.* Several experiments of both long and short terms have been carried out in recent years to test various methods of utilising straw on the land. The Rothamsted Report for 1946 contains a summary of the results of a four-course experiment started in 1930. A similar summary is given below for a three-course experiment commenced in 1933 in Long Hoos Field, Section VI.

The main purpose of the experiment is to study the immediate, residual and cumulative effects of straw-ploughed in and made into compost. All plots receive equal amounts of N, P, K fertilisers; half of the plots receive raw straw in addition and one-quarter receive a compost made from the straw and the fertilisers. The treatments tested are:—

Ar Fertilisers only, no organic manure

Ad Straw made into compost and applied in autumn

St1 Raw straw ploughed-in in autumn, fertilisers in spring

St2 Raw straw ploughed-in in autumn, half the fertilisers applied in autumn and the remainder in spring.

These treatments are applied to their respective plots in alternate years, so that both the immediate and the residual effects are measured. The eight treatments are repeated three times in each block. There are three blocks cropped with potatoes, barley, sugar beet, which follow one another in that order. The straw applied directly to the land or used to make compost is at the rate of 53·3 cwt. per acre. The fertilisers provide 0·4 cwt. N, 0·4 cwt. P_2O_5 and 0·5 cwt. K_2O per acre. On the compost plots the whole of the nitrogen and phosphate fertilisers are used to rot the straw, the potash fertiliser being applied separately in spring. In addition to these treatments all sugar beet plots receive 0·2 cwt. N, 0·2 cwt. P_2O_5 and 0·25 cwt. K_2O per acre, and all potato plots double these amounts.

The average yields over fourteen seasons are given below:—

3-course rotation experiment—Rothamsted
Mean yields per acre, 1934 *to* 1947, *inclusive.*

		Potatoes	Barley		Sugar Beet		
			Grain	Straw	Washed Roots	Tops	Sugar
		tons	cwt.	cwt.	tons	tons	cwt.
Immediate effects							
Yields in year of application							
Ar	No straw	9·15	32·3	37·4	11·60	10·63	43·5
Ad	Straw-compost ...	7·89	27·6	29·8	9·88	8·09	37·3
St1	Raw straw, fertilisers in spring	9·70	30·8	34·5	10·91	9·32	41·4
St2	Raw straw, fertilisers in autumn & spring	9·20	30·7	32·8	11·05	9·29	42·0
	Mean ...	8·99	30·4	33·6	10·86	9·33	41·1
Residual effects							
Yields in year after application							
Ar	No straw	6·95	27·4	29·1	10·07	8·16	38·0
Ad	Straw-compost ...	7·42	26·0	28·3	9·78	8·11	36·9
St1	Raw straw, fertilisers in spring	7·97	26·9	29·0	10·13	7·84	38·2
St2	Raw straw, fertilisers in autumn & spring	7·96	27·8	29·9	10·30	8·36	39·1
	Mean ...	7·58	27·0	29·1	10·07	8·12	38·1

In the year of application both raw straw and straw compost reduced the yields of barley and sugar beet. The reduction was particularly noticeable in barley straw and sugar beet tops, both of which are sensitive to the supply of available nitrogen. These results show that straw locked up some of the fertiliser nitrogen in forms which did not become available to the immediately following crop.

In the year of application potatoes gave different results from barley and sugar beet. Provided the fertilisers were applied in the normal way in spring, ploughing-in straw during the previous autumn gave 11 cwt. per acre more potatoes. Where half the fertilisers were applied in the autumn with the straw there was no such benefit from straw. These results suggest that the benefit from ploughing-in straw is mainly physical. For potatoes, but not for sugar beet and barley, this improvement more than makes up for the inevitable loss of immediately available nitrogen as the straw decomposes, provided that the nitrogen fertiliser for the potatoes is held over until spring. Straw compost gave much lower yields than fertilisers alone for all three crops.

The residual effects on the second crop after application were somewhat different from the immediate effects. Straw ploughed-in had negligible residual effects on sugar beet and barley but had marked residual effects on potatoes, both series of plots with straw ploughed-in giving 20 cwt. per acre more potatoes than plots without organic manures. The plots with residues from straw compost gave lower yields of sugar beet and barley but higher yields of potatoes than those without organic manures.

The results as a whole show that ploughing-in straw improves the physical properties of this heavy soil and gives better yields of potatoes. The straw locks up available nitrogen and it is necessary to give additional nitrogen fertiliser to the following crops. This extra nitrogen should be given at the normal time for the crop and not applied with the straw. Composting straw locks up available nitrogen and composts should not therefore be regarded as effective substitutes for inorganic nitrogen.

From 1934 to 1937 the experiment also included tests on the effects of autumn-sown rye and vetches or catch crops. Rye between barley and sugar beet averaged only 3·4 tons green stuff per acre and the rye between the other crops were much smaller. The vetch crops were very small. The rye reduced the yields of the following crops, the reduction being largest for barley grain and straw and sugar beet tops. The rye, like the straw, reduced the amount of nitrogen available to the following crops. The small crops of vetches had negligible effects apart from a small reduction in the potato crop.

In 1942 the sugar beet crop showed symptoms of magnesium deficiency, which was confirmed by leaf analysis. Magnesium sulphate at 2·5 cwt. per acre was added to some of the sugar beet crops in each subsequent year but there were no effects on yields and the symptoms of the deficiency were not observed again.

THE FARMS

By J. R. Moffatt

Rothamsted

The management of the Rothamsted and Woburn Farms was merged in October, 1946, and this necessitated a reorganisation of the administrative staff. Mr. C. R. L. Scowen was appointed in October, 1946, to assist with the management of the Rothamsted Farm, while Mr. G. F. Cole relinquished some of these duties to assist with the general management and supervision of field experimental work at the Woburn Farm. The field staff, led by the farm foreman, numbered about 20, and included 4 German prisoners of war who were billeted on the farm. It was only through the splendid efforts of the staff, working as a team, that the effects of the year's very adverse weather conditions were not more serious. Most of the field operations needing much hand labour were done by German prisoners working under contract, as this proved the only satisfactory method of engaging gangs. Potato planting and picking, and the singling, side-hoeing and harvesting of the mangolds and sugar beet were all carried out in this manner.

In 1947 the area of land farmed at Rothamsted totalled 503¾ acres, of which 345¾ acres were under tillage. The area of permanent grassland was 127½ acres, of which 62 acres were under long-term experiments, 26 acres were rented grazing, and the remainder mostly unploughable ground because of the presence of tree-stumps, etc. Of the arable crops, barley occupied the biggest area (90¾), followed by wheat (60½), and potatoes (30¾). Other crops included oats, linseed, beans, kale, mangolds, sugar beet and rye. The area under temporary leys was 98¼ acres.

Compared with 1946 these figures show a slight increase in the tillage area, with a corresponding decrease in the permanent grass. The area under the various crops remained much the same as in previous years, except that barley increased by 20 acres, and 19 acres were under linseed, which crop was not grown in 1946. In the late spring of the year 19½ acres of old grassland were ploughed up, and as the wireworm infestation, as shown by counts made on soil samples, was heavy, linseed and kale were the first crops taken, these crops being more resistant to damage by this pest than most other crops.

The number of experimental field plots laid out during the year numbered 1,479, rather less than usual. However, the increasing complexity of the experiments and the extremely unfavourable weather conditions in autumn and spring made it impossible to handle successfully any more plots. A detailed description of the field experiments carried out is given in the report prepared by the Field Plots Committee.

The predominant factor governing field work in any year is the weather, and in the season under review conditions were almost as unfavourable as they could be. All extremes of weather were encountered; the winter was the severest in living memory, and this was followed by a very dry, hot spell lasting throughout most of the summer and autumn. Rainfall varied from 5·74 in. in November, 1946, to 0·10 in. in October, 1947. The total rainfall for 1947 was

only 22·08 in., almost 6½ in. below the average, while even after the long, hot summer the total hours of sunshine were 12 below average. Despite the long, cold winter, however, and a mean temperature in February of 11·4° F. below the average, the mean temperature for the year was 10° F. above the average, each one of the last nine months being warmer than usual.

The late harvest of 1946 and the large acreage of potatoes grown delayed the start of winter corn sowing. The very wet weather in November, 1946, when there were 23 wet days, with a rainfall of well over twice the average, considerably hampered this work. Little more than half the scheduled wheat acreage was sown, and part of the area not sown to wheat was sown to barley in the spring.

Frosts were almost continuous from December, 1946, to mid-March, 1947, and the thermometer did not rise above freezing point at all between the 11th and 25th February. On 24th February the screen temperature fell to 4·4° F., 27·6° of frost. Snow which fell in January was added to in February and March, and did not start to melt until mid-March. With the thaw came floods, and the lowest parts of most of the fields were under water for several days. A gale followed, with gusts up to 60 m.p.h., which stripped the roof from the feeding stuffs loft and blew in a large part of the brick gable end of the building. Trees were brought down, and many stacks were disturbed.

Throughout this period no land work at all was possible; and in the 5 months ending 31st March land work was possible on only 30 days. However, the farm staff were gainfully employed, mostly under cover, during the whole of this period, either sorting potatoes stored in large heaps under the Dutch barns or threshing the 1946 corn crops stored in outside stacks and in the barns. The average yields per acre for 1946 over the whole farm were:—wheat, 28·13 cwt.; barley, 20·9 cwt.; oats, 21·3 cwt.; and beans, 18 cwt.

The damage resulting from this severe winter, though serious, was not as devastating as was at one time feared. Most of the winter wheat survived, although the plant was thinned and patching was needed on some areas. No winter oats or barley had been sown. The winter beans, which were sown very late in the autumn, were severely damaged, and there were not sufficient plants left to warrant leaving the crop. Most of the leaves and stems of clovers were killed, but the crowns survived and the plants were able to re-establish themselves. Part of the kale crop which had not been consumed was destroyed, and the mangolds in an outside clamp were damaged.

Land work in spring could not start until early April, about 5–6 weeks later than usual, and throughout the season each operation was, as never before, a race against time. However, the handicap at the start was so great that none of the spring sowing operations could be done on time. Fortunately a spell of fine weather followed, and by working all the hours of daylight, 7 days a week, the spring cereals, sainfoin, and grass and clover seeds were sown by 20th April. The preparation of the ground for root crops followed, without interruption, as May was drier than usual, but a spell of very hot weather in the middle of the month, and another at the end, caused the surface of the ground to dry out, and considerably delayed the germination of these late-sown crops.

By early June the field work was up to schedule. The winter wheat then looked rather disappointing, as it appeared to have thinned out considerably, despite top-dressings of nitrogenous fertiliser; the spring corn and linseed looked very satisfactory; the kale had escaped serious damage by fleabeetle and that grown after old grassland heavily infested with wireworm did not appear to suffer damage by this pest; the sugar beet, although rather irregular, was making headway; the mangolds had germinated unevenly and looked very backward; many of the potatoes were not yet through the ground.

The thinness of the wheat crops enabled the weeds to grow rather more freely than usual, and to control them most of the wheat areas, and some of the barley, were sprayed with a salt of D.N.O.C., or dusted with a proprietary weed killing powder, with satisfactory results. One area of old grassland (Great Knott 1), which had not been ploughed since 1928, and which was ploughed up in late March and sown to kale, was heavily infested with Fat Hen (*Chenopodium album*) and yellow charlock. It seems likely that the seeds of these weeds have remained viable for nearly 20 years, merely awaiting suitable conditions for germination. Wild oats (*Avena* spp.), which originated in the continuous corn growing experiments in Broadbalk and Hoosfield, where they have assumed serious proportions, seem to be spreading over most of the farm. It is hoped to keep this weed under control, however, by reducing the number of corn crops grown in succession on any one area.

The growth of the hay crop was slow after a late start, and only a light crop was made in June. However, it was secured in excellent condition. In July the rainfall was almost an inch below average, and this proved to be the start of a very dry spell which lasted until early December. In each of the months July–November, 1947, the rainfall was well below the average, and the total for this period was only 4·46 in. compared with the average of 13·39 in., i.e., only one-third of the average. October, usually the wettest month of the year, yielded only 0·10 in.

The dry weather caused a rapid ripening of the corn crops and enabled the harvest to be gathered in in record time, the operation being completed by the end of August, which month had 271 hours of sunshine, 86 hours above the average, with a mean temperature 9·4° F. above the average. None of the corn was lodged, and most of it was carted without stooking and was stacked in the Dutch barns, while the remainder was threshed in the field. Threshing is not yet completed, so yields are not available; wheat yields will probably be considerably below, and barley and oats a little below normal. The main area of linseed produced a heavy crop, and the estimated yield is at least 12 cwt. per acre. As no seed of the variety "Royal" was available the variety "Bison" was sown, along with a little American seed. The heavy crop was cut with a binder and proved a slow and tedious job. The sheaves were turned after lying for three days, and carting followed two days later. A smaller area of "Redwing" was grown in a field where wheat had failed owing to severe wireworm damage. This crop was sown rather late, and was affected by the drought. The estimated yield from this area is 7 cwt. per acre.

Normally, potato lifting closely follows harvest, but this year there was a considerable interval as corn harvest finished early, while owing to the late planting and dry season the tops of the potatoes remained very green until mid-October. There was no late blight this year, and as the weather conditions were unfavourable to the disease no preventative routine spraying was done. The start of lifting was delayed to give the crop a chance to put on more weight. The experimental plots were lifted at the end of September, but the main area of non-experimental potatoes was not lifted until the latter half of October. Even then the tops were green and vigorous, and had to be burnt off with acid before lifting could commence. Yields were lower than usual, and the tubers smaller, but considering the lateness of planting and very dry season the estimated yield of 7–8 tons per acre must be considered satisfactory. The ground was very hard and dry, and resisted the penetration of the lifter blade, which resulted in more damage than usual to tubers. Most of them were stored in large heaps within straw bale walls to a depth of 12 ft. under the Dutch barns. In order to get the sacks in which the potatoes were carted from the field up to this height a sack-elevator was used very successfully, resulting in a big reduction in strenuous manual labour.

The lifting of the mangolds followed, but this crop was very disappointing, having suffered severely from the effects of late sowing and drought. The roots were generally very small and yields low. The crop was lifted by the end of October and was carted and clamped under good conditions.

The lifting of the sugar beet crop presented grear difficulty, as the ground was so hard that it was extremely difficult to keep the beet lifting plough in the ground. This resulted in the ends of a large number of roots being broken off. The roots were easier to clean than ever before, however, and the whole operation was completed by mid-November, about three weeks earlier than usual. Yields were well below average, but this was mitigated to a certain extent by the very high sugar content. The main beet experiment gave an average yield of 8·75 tons per acre of clean beet, with an average sugar content of 20·53 per cent., a sugar yield of 36·3 cwt. per acre.

Autumn ploughing was seriously impeded by the hard state of the ground and the shortage of plough-shares. Some of the fields were in fact too hard to plough at all, and those which were ploughed turned up very hard and dry, and needed a lot of working to get a suitable seed bed. Because of these hard, dry conditions the drilling of winter corn and beans was delayed, but as the drought remained unbroken by the end of the third week in October seed beds were forced by the use of cultivators and rollers. By the end of the month, with the drought still unbroken, most of the winter corn and beans were sown. Certain areas were still too hard to plough, and the cropping schedule had to be revised accordingly. Approximately 90 acres of winter wheat were drilled, the main varieties being Bersee and Squareheads Master 13/4. The winter bean area was destroyed by birds where the seed was drilled, but where the seed was dropped into the furrow bottom during ploughing little damage has been done. In future, beans will be either placed

in the furrow bottom or will be broadcast on the surface of the ground before ploughing and then ploughed in. In the past, both these methods have given satisfactory results.

Only a few small areas were undersown with grass and clover seeds during the year, and most of these survived the drought. The area undersown with sainfoin had to be ploughed up as the plant was too thin to warrant leaving it.

Rainfall during December was heavier than usual, but it was not until the middle of the month that the rain reached ploughing depth. Conditions for ploughing were then excellent, and most of the winter ploughing was finished by the end of the year.

The season was an extremely unfavourable one for livestock. Fortunately the cattle survived the hard winter without losses or serious setbacks, although they made heavy inroads into the stocks of hay. A bunch of Irish bullocks was purchased in the autumn of 1946, and most of these were out-wintered with the intention of selling them fat off the grass during the summer of 1947. However, as a result of the hard winter they were in rather poor condition by the spring, and just as they were beginning to thrive really well the drought caused a severe shortage of grass. This resulted in only a few of the cattle being fattened from the grass, and to get these away they had to be fed liberally with kale and concentrated feeding stuffs. Several of the more forward beasts were brought into the covered yards in the autumn of 1947 to fatten by Christmas. The less forward beasts lived during September, October and November mainly on barley straw, helping themselves from stacks built in the grass field from the 1946 and 1947 crops. They maintained their condition on this diet but will have to be over-wintered again before being fattened off during the summer of 1948. The position was aggravated during the summer as owing to the very severe effects of the drought on grass on the light Woburn soil some of their cattle had to be transferred to Rothamsted. During the summer the Blue-grey and Kerry cows, which had been kept to rear stock of known history for grazing experiments, were sold. Most of them were about twelve years old and fetched more than their original price. No new breeding policy has yet been formulated as this will depend to some extent upon the programme of field experiments now under consideration. Most of the calves reared by these cows during 1945 and 1946 are still on the farm, and will be used for the last season of the grazing experiment comparing the residual value of feeding stuffs with the conventional estimates of their manurial value applied as fertilisers.

Sheep, too, survived the hard winter without loss and appeared to maintain their condition. Fortunately, lambing did not commence until the weather improved, and the 100 Halfbred ewes reared 163 lambs. The shortage of grass considerably reduced the milk yield of the ewes and consequently the lambs did not do as well as was expected. Weaning was delayed for this reason, and owing to the absence of fresh grass for the lambs they were almost immediately folded on to the kale. Most of them were sold fat by the end of the year. About 30 of the most forward ewe lambs of the 1947 crop were tupped in the autumn of 1947 by a Suffolk ram, and about 30 of the cross-bred ewe tegs of the 1946 crop were

retained for the breeding flock. Several of the old ewes which would normally have been culled were also retained in the flock for another year, and a few of the best ewes from Woburn were transferred to Rothamsted. The rams used for the production of fat lambs were Oxfords and Suffolks.

The use of purchased feeding stuffs for livestock was almost eliminated, the only exceptions being the sugar beet pulp allotted to us as growers and certain feeding stuffs required for the animals on experiments. The protein-rich food in the home-produced rations consisted almost entirely of beans.

During the period between the end of harvest and potato lifting general estate maintenance work, including hedge trimming and the removal of barbed wire from around the Manor House, was undertaken. This work was continued after beet-lifting had finished, and all hedges were finished, but a lot of work remains to be done before the grounds of Rothamsted House attain their pre-war condition.

Work was commenced on the much needed new road between the farm and laboratories, and six new cottages for farm workers are in course of erection. No additions to the farm buildings were made, although new office accommodation was provided by the conversion of buildings previously used for other purposes.

The farm was worked, as in the past few years, by 4 wheeled tractors and 2 teams of horses, the latter used mainly on the experimental plots and for carting. Little new equipment was purchased, other than the sack elevator and a small rotary hoe for keeping clean the paths in the experiments.

The year under review was an extremely difficult one from the farming point of view. A wet autumn followed by the severest winter in memory caused all operations to be rushed in a vain attempt to make up for the late start. It was disappointing that the results of the tremendous efforts made in the spring were not fully realised because of the severe drought which lasted throughout the summer and autumn. This greatly restricted the growth of all crops and resulted in yields which were generally well below our average. The dry conditions also hampered the preparation of the ground for the 1948 crops, but it is hoped that more normal weather will prevail in 1948 so that crop yields will be a truer reflection of the work involved.

Woburn

On 1st October, 1946, the management of the Woburn Experimental Farm was merged with that of the Rothamsted Farm, and this report covers the first year's work.

Prior to 1947 considerable emphasis had been laid on market garden crops which, with sugar beet and some potatoes and barley, formed the main arable crops. There was also a considerable area of poor quality grassland but the only stock kept was a very small pig herd and a small sheep flock kept primarily for experimental work on Swayback disease in lambs. The market garden crops demanded more labour than seemed justified on an experimental farm, and the time taken in the marketing of the small amount of produce seemed out of proportion to the returns. It was therefore decided to abandon the growing of non-experimental market garden crops.

The main objectives in the first year were:—

1. To retain the existing experimental field programme and to prepare other potential sites for field experiments.

2. To clean the arable land of twitch and other arable land weeds by increasing the area under cleaning crops such as potatoes, or, where necessary, by fallowing.

3. To increase the productivity of the arable land by better and more timely operations, by the increased use of fertilisers, especially nitrogenous fertilisers, and by the employment of seasonal labour when required.

4. To reduce the area of grassland by ploughing up the least productive grass, and to increase the productivity of the remaining grassland by increased stocking and proper management, and the judicious use of fertilisers.

5. To provide such new implements and machinery as were required to replace worn out equipment.

However, the year proved a very difficult and disappointing one, due very largely to the wide extremes of weather which prevailed. This factor severely hampered the execution of the work planned, and throughout the whole year each farming operation was, as never before, a race against time and many of the results have been disappointing.

Of the 128¾ acres farmed in 1947, 42 acres were under cereal crops, 13½ acres under potatoes, and 6½ acres under sugar beet. Grassland occupied 45 acres, 16 acres were bare fallowed and 5¾ acres were under sundry experimental crops. The number of experimental field plots was restricted to 330, though as on some areas two crops were taken the total number of plots harvested was 450. A more detailed report on the individual experiments will be found in the report of the Woburn Station.

The season started off well with a fine and dry October, which enabled the small potato crop to be gathered under excellent conditions and the autumn ploughing to make good progress. Unfortunately the weather then broke and in the months of November and December the rainfall totalled almost 7 in. compared with the average of 4·6 in. The harvesting of the sugar beet crop was seriously delayed and was not finished until early in January, 1947, and only a small proportion of the area scheduled for winter corn could be sown.

There followed a spell of unprecedently hard weather with almost continuous hard frosts and heavy falls of snow. On two nights in February the minimum temperature fell to minus 4° F and minus 5° F., and the mean for the month was 22·3° F. compared with a normal mean of 33·0° F. The snow did not melt until the end of March, and gave a rainfall figure of 4·72 in. for the month compared with the average of 1·76 in. No land work at all was possible from early January until the end of March, and this put the spring programme of work very seriously behind schedule. Many of the plans for thorough cleaning operations before spring sowings had to be abandoned, and all field operations had to be hurried through to make up for lost time. The small areas of winter wheat, rye and barley survived without damage.

Fortunately the months of April and May were generally favourable to land work, but though operations were pushed ahead

as rapidly as possible all crops were sown late. In April 8½ acres of grassland were ploughed up and sown to barley almost immediately. Potatoes were the last crop to be planted and this operation coincided with a spell of very hot weather which dried out the ground very rapidly.

The rainfall in May was only about half the normal, and this proved to be the start of a severe drought which persisted for almost 7 months. In each of the 7 months May to November, 1947, the rainfall was below normal, while the total for the period was only 6·23 in. compared with the average of 15·42 in. This lack of rain combined with temperatures well above the normal severely restricted the growth of crops. Corn crops were least severely affected and most of them looked satisfactory; the only exception was an area of Bersee wheat sown late in spring, which, despite very heavy top dressings of nitrogen made only very slow growth. Growth of sugar beet and potatoes were obviously retarded; the sugar beet wilted considerably during the long hot days; the potatoes, especially the late planted ones, were slow in coming through and then only grew slowly; grass made very little growth and by the end of July was completely burnt up, the grassland appearing not unlike stubble fields. The one hay field gave only a very low yield despite a top dressing of 3 cwt. of sulphate of ammonia, and all the undersown seeds were burnt up just after harvest. The effect of the drought on the individual experimental areas is described in the report of the Woburn Station.

The weather was ideal for operations on the fallow ground for the eradication of twitch. Three areas in Stackyard field were fallowed; the permanent wheat plots to eradicate creeping soft grass (*Holcus mollis*), the permanent barley plots to eradicate creeping soft grass and Fiorin (*Agrostis stolonifera*), and series C, not at present under experiment, to eradicate Fiorin. Wild Oats (*Avena* spp.) were also prevalent in the permanent barley plots, with some on the wheat plots, but it is unlikely that the fallowing did much to reduce the number of seeds of this weed as the ground was too dry for germination.

Conditions for harvesting were ideal and all crops were carted with a minimum of labour, many of them without having been shocked. The Rothamsted harvesting technique was used for the first time on the experimental plots, and threshing was done soon after harvest with a small portable machine from Rothamsted. The overall average yield of barley was just over 18 cwt. per acre, and of wheat (including the disappointing area of spring wheat) just over 14 cwt. per acre.

Potato lifting was delayed until towards the end of October as the tops remained green and the tubers appeared to be still growing. The tops were burnt off with sulphuric acid to facilitate the lifting, while the picking was done by German P.O.W. labour. The crop was cleared under excellent conditions, and the estimated yield of 6 tons per acre, though low, must be considered reasonable for the season. The crop was stored under cover so that sorting would provide a wet weather job during the winter months.

Sugar beet lifting followed and was done by the regular staff. The roots were very small but the sugar content, especially of the

beet lifted first, was high. Yields were approximately 6 tons per acre of clean beet with an average sugar content of 18·9 per cent.

The early completion of harvest should have provided the opportunity for thorough cleaning operations in the autumn, but the ground proved to be much too hard for this work. The ploughing of stubbles had to be abandoned for the same reason, and though the ground gradually became softer some of the fields could not be ploughed satisfactorily until late November. On some of the land which might have been ploughed earlier the work was held up by the scarcity of plough-shares. The difficulty in preparing the land prevented the sowing of autumn wheat on most of the area scheduled for this crop.

Livestock

Twenty-one Irish crossbred cattle were purchased in the autumn of 1946 to graze down the understocked grass and to make farmyard manure in covered yards during the winter. It was hoped that the beasts would fatten on the grass during 1947. However, the grass made such little growth that there was no hope of fattening these beasts and ten of them were transferred to Rothamsted in June. The remaining eleven had insufficient grass on which to fatten, so they have had to be yarded again as stores for the winter of 1947–48 as there is insufficient hay and feeding stuffs on which to fatten them in the yards.

The ewe flock, which consisted mainly of very old ewes of very mixed breeds and crosses, suffered severe casualties during the year; 20 of them died, mainly through old age. Those that survived produced a small crop of weakly lambs which have not done at all well. There were only about 6 ewes worth retaining, and these were transferred to the Rothamsted flock. The remainder of the old ewes were transferred to Rothamsted for fattening off on kale, and after the 1947 lamb crop has been disposed of the land at Woburn will be rested from sheep for one or two years.

The pig herd, which had been maintained at 5 breeding sows during the war years, has been increased rapidly by retaining some of the best of the home bred gilts and by the purchase of small gilts from other herds. Most of the young pigs reared have been sold locally for fattening, many of them to members of a local pig club.

Implements

During the year considerable progress has been made in re-equipping the farm with modern implements to replace old and unreliable ones.

Summary

The year 1946–47 has been a very difficult one, with many disappointments and much frustration, due almost entirely to wide extremes of weather conditions. The time lost in the late autumn, winter and early spring was never regained, while the severe drought considerably reduced growth of all crops and so affected yields considerably. Although it was not possible to execute much of the work which was planned, considerable improvements have been made during the year, and plans are prepared for a considerable expansion of output in 1948.

WOBURN EXPERIMENTAL STATION

By H. H. Mann

The general design and the principal results of the long-term experiments at Woburn were outlined in the Report for 1946 and are not repeated here.

The Station is on a light sandy soil, very deficient in lime and over a great depth of sand derived from the Lower Greensand. These conditions provide a great contrast with those at Rothamsted. The whole of the farming operations are much more influenced by weather conditions, especially by long and persistent droughts. On such a soil the conditions of 1947 were particularly trying. The winter precipitation was heavy for all months with 4·75 in. in November, 1946, and 4·89 in. in March, 1947. Frost and snow delayed the commencement of spring work, and there ensued a summer of almost unprecedented dryness, the rainfall from April to October being only 6·61 in. against a normal of 14·63 in. This did not seriously affect the yields of crops which had become well established before the long dry spell set in, but the effect on crops sown later or transplanted was disastrous; the yield of grass in the later part of the season was very small indeed.

A. Field experiments

1. *Continuous wheat and barley experiments*

The area which has been devoted to continuous wheat and barley growing since 1877 had become, for the third time since the experiment was started, so very weedy in 1946 that it was resolved to fallow the whole area, with frequent cultivations. So far as the wheat area is concerned the chief weeds have been the two grasses, both well known "twitches", *Holcus mollis* and a variety of *Agrostis* (probably *A. gigantea* var. *dispar*). These two grasses, which first became serious on the plots where, owing to acidity, wheat would no longer grow, gradually overspread the whole wheat area. With the usual amount of cultivation the *Agrostis* was gaining ground on the *Holcus*, but when an extra amount of autumn cultivation was given (as in 1945) the former almost disappeared while the *Holcus* was more in evidence than ever in the following year. It remains to be seen what relative effect the very intense cleaning of the land during the whole of the year 1947 has had on the two grasses, and observations on this point will be made during 1948.

The weed herbage of the continuous barley area was of a different character. Here, though the "twitches" were present, *Holcus mollis* was only found in small amount, and *Agrostis* was much less abundant than on the wheat area. On the other hand, wild oats, which were a comparatively unimportant pest till 1943, had increased so much in 1945 and 1946 that the crop of barley was very largely stifled. The phenomenon of the sudden rise of this weed to the position of a serious menace has been noticed in many parts of the country.

2. *Maintenance of fertility of light land*

One of the purposes of the Woburn Station is to determine the best method for the maintenance of the fertility of light land.

Several long-term experiments have been in progress for a number of years on problems of special importance at the present time when the amount of farmyard manure available is becoming less and less. Reports on these experiments for 1947 are given below.

(a) *Alternate husbandry experiment.* Four rotations are compared:—

(i) Three years' ley, grazed

(ii) Three years' lucerne, cut for hay

(iii) Potatoes, wheat, one year ley cut for hay

(iv) Potatoes, wheat, sugar beet (previously kale)

and their effects on soil fertility are tested by the yields of potatoes followed by barley. The results in 1947 were generally similar to those in the preceding six test seasons, though the potato crop was small. The yields of potatoes after grazed ley or hayed lucerne were higher than after the arable rotations. The response of the potatoes to farmyard manure was less after grazed ley than after the other rotations.

(b) *Six-course rotation experiment on inorganic fertilisers.* The 1947 crops were the eighteenth in this experiment, which tests the effects of increasing amounts of N, P and K fertilisers on a rotation of barley, clover, wheat, potatoes, rye and sugar beet.

In 1947 there were clear responses to sulphate of ammonia applied on 17th April to barley, wheat and rye before the drought began to be serious but there was little or no response when the sulphate of ammonia was applied later to sugar beet (1st May) and potatoes (12th May).

(c) *Green-manuring experiment.* This experiment was laid out in 1936 and re-designed in 1945 to test the effects of ryegrass, clover (both undersown in the previous crop of barley), rape, lupins and fallow as preparations for cabbages transplanted in July and followed by barley. The results in 1947 were unusual. Plots which had carried good crops in the first half of the season were very dry when the cabbages were transplanted. The best cabbages were on the plots which had a bare fallow, and the worst on those where a large amount of clover or ryegrass was ploughed in shortly before the cabbages were transplanted. The barley crop showed similar results for the organic matter ploughed in during the summer of 1946. In the exceptional 1947 season the crops were smallest where most organic matter had been ploughed in.

(d) *The making of a market garden soil.* This experiment was started in 1942 to determine the relative value of farmyard manure, vegetable compost, sewage sludge and a compost made from sewage sludge and straw on a two-year rotation, viz., green peas and leeks, globe beetroot and winter cabbages. The year 1947 was a particularly difficult one for this experiment. The globe beetroot crop was late and the winter cabbage crop which followed it failed. The leek crop had to be watered twice to save it. The globe beetroot gave poor results with sewage sludge alone or in compost, but the green peas and leeks behaved similarly with all the organic manures. Crops, especially green peas, on plots without organic manures showed much greater effects of the drought.

3. *Other field experiments*

For a number of years the Woburn farm has taken a share in the study of certain exotic crops which it was thought might be suitable for cultivation in this country. Three of these crops have again been grown in 1947, namely soya beans, an early ripening maize, and two varieties of sweet lupins. The year under report was favourable to all these crops. All seemed to have less difficulty than our local crops in establishing themselves under conditions when the soil was rapidly drying up, and the high temperatures which followed proved very favourable to the ripening of crops which do not mature easily in England.

The Manalta maize, which we originally got from Canada, sown on 5th May, ripened well and was reaped on 15th September, almost a record for this country, and gave a good crop. Several types of maize received from Canada, however, reputed to ripen in 95 days, but planted on 13th June, failed to ripen at all. The times of ripening given in the literature for varieties have evidently no meaning for this country with its much cooler summer than the areas where maize is usually grown.

The experiments with sweet lupins have led to two results. The first is that the amount of fodder that can be obtained from a yellow sweet lupin crop on the very suitable soil of Woburn was 14½ tons of green material per acre. This was grown between 22nd May and 21st August, or in 91 days. Though classed as a sweet lupin it was still somewhat bitter and sheep did not take to it readily, but ultimately ate at least all the leafy parts. The second point refers to the very great attractiveness of sweet lupins to rabbits, and the sweetest of the lupin varieties was eaten out completely in the area which was not specially protected.

B. Pot experiments

1. *Clover sickness*

Results of earlier work have been confirmed and, in addition, it was found that although fertilisers alone make very little difference to clover sickness, fertilisers combined with lime have a distinctly beneficial effect. On the other hand increasing the acidity of the soil at least to a pH value of 5·4 does not cause the soil to show symptoms of clover sickness.

In experiments on soil temperatures, partial waterlogging and the proportion of clover to soil, it was found that soil kept at 30° for a whole season showed more signs of clover sickness than any of the other treatments.

2. *Competition of crop plants and certain weeds*

Results on the competition of barley and *Agrostic* twitch were closely parallel to those already described with *Holcus mollis*.

3. *The nutrition of crops under very acid soil conditions*

In 1946, for the first time a healthy crop of barley had been grown in a soil at pH 4·3 after adding a large amount of soluble phosphate and a little calcium nitrate to the soil. In 1947 this was repeated without the addition of calcium nitrate and large plants were obtained, though with very little grain. Other crops reacted differently. Lucerne gave an abundant crop with soluble phosphate

alone though the plants hardly grew on the untreated acid soil. With mustard the effect of phosphate was much smaller and with carrots it was very small.

C. Laboratory work

An investigation has been commenced on the sulphur present in various forms in soil samples taken at various intervals since 1876 from the Permanent Barley plots.

D. Staff

The Woburn Experimental Station has been under the charge o Dr. H. H. Mann during the whole period under report, while the farm has been under the management of Mr. J. R. Moffatt, who has directed the work from Rothamsted. Mr. T. W. Barnes has been chemist to the Station since 1929 and has remained in charge of the laboratory during the present year.

THE ELECTRIC CHARGE ON SOIL PARTICLES

By R. K. Schofield

Experimenting both in his laboratory and in his garden near Moscow in 1808, Reuss found that water in contact with soil carries a positive electric charge in consequence of which it is transported towards a cathode. In this way he discovered the phenomenon now known as electro-osmosis. Nearly half a century later, Thompson and Way discovered the phenomenon of base exchange in soil. For many years these two phenomena were separately investigated: the first by physicists, and the second by chemists. The artificial division between these investigations retarded progress, and the realisation that both phenomena have the same root cause is a comparatively recent development. One object of the physico-chemical studies conducted in the Physics Department has been to establish the nature of the electric separation in soil. For while electro-osmosis and base exchange provide the clearest evidence for electric separation it influences both the physical and the chemical behaviour of soil in other ways.

The fact that clay soils shrink when dried, and swell again when rewetted, leads to the conclusion that the particles are not in solid contact but are separated by water films. It is now clear that the exchangeable cations play a dominant part in maintaining these water films and regulating their thickness. In this phenomenon the chemical nature of the exchangeable ions profoundly influences the physical effects they produce.

In connection with the availability of exchangeable cations as plant nutrients the fact that they are held by electrostatic attraction to negatively charged soil particles is of great significance, and it is not surprising that investigations with a purely chemical outlook, which take no account of the powerful electric fields close to soil particles, have achieved only a limited success.

It has become increasingly clear that as far as possible all the consequences of electric separation must be considered in relation to one another, and that the artificial distinction between physics and chemistry must be completely broken down. The undertaking is formidable, and much groundwork is needed before results can be obtained that bear directly on the very complex conditions actually existing in field soil.

Measurement of the electric charges on soil particles

Ionic exchange provides the only reliable method for measuring the net electric charge carried by a particular sample of soil. Since the charge depends to some extent upon the nature and concentrations of the ions in the solution surrounding the soil particles these must be controlled or determined at the same time. Hitherto most methods used for determining exchangeable cations have been designed for the routine examination of large numbers of soil samples, and have been considered satisfactory so long as they were reasonably rapid and furnished reproducible results. For precise

measurement of net charge no existing method was found to be entirely satisfactory. Control of aluminium ions has been the main problem.

A technique has now been worked out which effectively prevents disturbance from aluminium ions from pH 2·5 to pH 8 (1). The belief generally held that clays lose their negative charge when in contact with solutions of low pH is ill-founded. The methods usually employed fail to detect the presence of exchangeable aluminium. When sufficient washings are given to remove the exchangeable aluminium it is found that the negative charge falls off much less with fall in pH than earlier work had indicated. For example, a sample of Rothamsted subsoil clay, which has a net negative charge of 27 milliequivalents per 100 g. when in equilibrium with a N/5 ammonium chloride solution at pH 7, has a net negative charge of 22 milliequivalents when the pH of the solution is reduced to 2·5.

By simultaneously measuring the retention of ammonium and chloride ions it has been found that only ammonium ions are concentrated close to the surfaces of the clay particles in the solution at pH 7. Chloride ions are actually repelled from the surfaces, which indicates that all the electric charges on the clay particles are of negative sign. In the solution of pH 2·5, however, chloride ions are slightly attracted. Compared with the condition at pH 7 about 2 milliequivalents of chloride ions are attracted to the surfaces of the particles. It thus appears that the 22 milliequivalents of *net* negative charge is made up of 24 milliequivalents of negative and 2 milliequivalents of positive charge.

An independent test fully supports this conclusion. It has been found that if the clay is repeatedly washed with acid ammonium oxalate in sunlight a photo-chemical action occurs resulting in the solution of iron and aluminium amounting to about 7 per cent. of the original weight. The residue is nearly white, and has a charge at pH 2·5 of close on 24 milliequivalents computed on the original weight. There can be no doubt that the positive charges present on the original clay when in the solution of pH 2·5 were on the hydrous oxides of iron and aluminium (which the oxalate washing removed), leaving the negative charges carried on the clay mineral proper. It was also observed that the residue repels chloride ions in the solution of pH 2·5, thus confirming that only negative charges are present.

These and parallel results with several other clays compel us to abandon the view hitherto widely held that between pH 3 and pH 7 clays greatly increase their negative charge by dissociation of hydrogen ions. No clay mineral so far examined has been observed to dissociate any hydrogen ions between pH 2·5 and pH 5 in N/5 ammonium chloride solutions. From pH 5 and pH 6 dissociation is just detectable, and it becomes progressively greater to pH 8—the limit of the present measurements.

The crystallographic study of the clay minerals has led to the view that isomorphous replacement should give rise to negative charges that are permanent in the sense that they cannot be increased and decreased reversibly by altering the pH, but can only be changed by processes that disturb the atomic arrangement within the crystals. Below pH 2·5 the charge diminishes but is not

restored again on raising the pH. There is other evidence that the clay mineral has suffered destructive attack.

It is entirely reasonable to suppose that the constant charge found between pH 2·5 and pH 5 is the "permanent" charge due to isomorphous replacement. It would be very desirable to check this conclusion by direct chemical analyses, but until the process for freeing clay minerals from contamination has been further refined this cannot be done.

It is also reasonable to attribute the progressive rise in the negative charge above pH 6 mainly to the dissociation of hydrions from hydroxyls attached to silicon atoms. Such hydroxyl groups occur round the edges of the silicon-oxygen sheets of the clay minerals and on the free silica. There is some evidence that the iron oxide removed by acid ammonium oxalate, besides carrying positive charges at low pH, may carry a few negative charges above pH 7; but this matter requires further study.

Negative adsorption and surface areas

Parallel with measurements of the electric charges on soil and clay, investigations have been made to elucidate the way in which electric separation influences soil properties. Mention has already been made of the repulsion exerted by the negative charges on the soil particles upon the free negative ions in the soil solution. By extending Gouy's theory of the diffuse electric double layer the relationship

$$\frac{\Gamma_-}{n} = \frac{q}{\sqrt{\nu\beta n}} - \frac{4}{\nu\beta\Gamma}$$

has been obtained (2). Here Γ_- is the "negative adsorption" of the repelled ion, n is the normality of the solution and Γ_-/n is a distance that conveniently expresses the extent of the repulsion. q is a factor depending on the valency ratio, ν is the valency of the repelled ion, β is a constant depending on the temperature and dielectric constant of the solvent, and Γ is the electric charge on the surface expressed in milliequivalents per square centimetre. This simple equation is valid so long as Γ is large enough for the first term to be several times the second, otherwise a more complex expression must be used.

This equation was first applied to existing data of Mattson for the negative adsorption of the chloride, nitrate, sulphate, and ferrocyanide ions by sodium bentonite. Dividing the negative adsorption per 100 g. of bentonite by the normality, and plotting this quotient against $q\sqrt{\nu\beta n}$, the points fall very well on a single straight line from the slope of which an area of 450 square metres per gram is obtained. From crystallographic data we find that pure montmorillonite completely dispersed into its constituent sheets would expose an area of 800 m.^{2} per gram. Measurements of negative adsorption were, therefore, made using a very fine fraction of bentonite separated with the aid of the supercentifruge. As it is difficult to handle this material except in a flocculated state, calcium chloride was used. Even so, the material could not be concentrated by centrifuging to more than 2 per cent. compared

with 10 per cent. used by Mattson. The measurement of negative adsorption in these circumstances requires high precision in the chloride determinations, and it was considered very satisfactory that none of the points deviated from a line for 800 m.^{2} per gram by more than the possible experimental error.

Measurements were also made of negative adsorption by jute (3) in solutions of lithium, sodium, potassium and calcium chlorides. With this material a small negative adsorption was found even in N/20 hydrochloric acid, in which case there would be scarcely any negatively charged carboxyl groups. It appears that about 11 per cent. of water is taken up by the solid matter, the chloride ions being too large to be admitted. In neutral solutions a large additional negative adsorption is found which clearly must be due to the repulsive action of the negative charges resulting from the dissociation of hydrions from the carboxyl groups.

Values ranging from 6 to 22 milliequivalents per 100 g., by means of cation exchange, were obtained for the carboxyl content of different samples of jute. It was found that the negative adsorption observed in the sample of lowest carboxyl content scarcely differed from the amount calculated by the use of Donnan's equation for the membrane equilibrium. Examination of the theory showed that this result is to be expected when the surface density of charge is low in relation to the distances separating opposing surfaces.

The sample with the greatest carboxyl content gave values considerably below the value given by the Donnan equation. The results obtained for solutions above N/20 indicated that in this jute the charges were spread over an area of 160 m.^{2} per gram. This is roughly a thousand times the external area of the fibres. At the same time an extrapolation of the values obtained in more dilute solutions shows that, in the limit, the chloride ions are completely expelled from 70 c.c. per 100 g. of jute. This is evidently the volume of internal passages within the jute fibres. The area of the walls of the passages being 160 m.^{2}, it follows that the average width of the passages is of the order of 100 Angstrom units.

Thus, by applying physical reasoning to chemical measurements, a new way has been opened up for the exploration of minute structures which are not regular enough to be investigated by X-ray diffraction, and could not be preserved in the high vacuum conditions needed for examination by the electron microscope. It can only be applied when the surface area is very large and when it carries a sufficient density of electric charge, but even with these limitations it should have a wide scope.

Film thickness

The same basic theory that yielded the equation for negative adsorption has been used to obtain the equation (4)

$$X = \frac{\pi}{\nu\sqrt{\beta c_0}} - \frac{4}{\nu\beta\Gamma}$$

for the thickness, X, of the water film on a surface carrying a surface charge Γ balanced by exchangeable ions of valency ν, which have a concentration c_0 at the outer surface of the film.

The theory shows that for equilibrium between the film and water in bulk there must be a pressure difference given by the Van t'Hoff equation

$$p_0 = RTc_0.$$

Deryaguin and Kussakov's determinations by optical interference of the thickness of water films between hydrogen bubbles and surfaces of mica and glass are in excellent agreement with the relationship to be expected between X and p_0. There is no adjustable constant in the theory so the test is a searching one. The results of their experiments with solutions of sodium chloride are not in satisfactory agreement with the theory. This is puzzling since over the same range of concentration the equation for negative adsorption seems to be entirely reliable. New optical measurements are being carried out with the help of Prof. L. C. Martin.

The theory indicates that p_0 is the repulsive pressure between two parallel opposing surfaces separated by a water film of thickness $2X$. We have here a basic concept upon which to build the theory of swelling and shrinking of clay. By itself the concept is too simple because it does not explain flocculation. In its simple form it may, however, be expected to give a fairly good account of the swelling of bentonite containing only monovalent cations.

Ionic equilibria

When a dilute solution is in equilibrium with a soil having sufficiently high density of surface charge, theory leads us to expect that the following "ratio law" will be obeyed (5):—

> When cations in a dilute solution are in equilibrium with a larger number of exchangeable cations, a change in the concentration of the solution will not disturb the equilibrium if the concentrations of all the monovalent cations are changed in one ratio, those of all the divalent cations in the square of that ratio, and those of all the trivalent cations in the cube of that ratio.

This ratio law has been tested for a number of ion combinations. Using soil from Park Grass Plot 7, that has received dressings of potassium and magnesium salts, a solution containing the chlorides of potassium, magnesium and calcium at a total concentration of N/100 was found, by trial, that would percolate unchanged through the soil. Another solution containing half the concentration of potassium and one quarter the concentrations of magnesium and calcium was then made up, and it was verified that this solution also would percolate unchanged through the same soil sample. The concentrations in these experiments were measured spectrographically in the Chemistry Department. In the majority of soils, calcium is the most abundant ion in the soil solution. These experiments and the theory they support indicate that the potash "status" of the soil should be judged by the ratio of the potassium ion concentration to the square root of the calcium ion concentration in a solution in equilibrium with it.

A further support to the "ratio law" was obtained in experiments with soil from Plot 9 (unlimed), which has become very acid after repeated application of ammonium sulphate. It was found that appreciable concentrations of aluminium ions and hydrogen ions must be present in the solutions in equilibrium with this soil.

Moreover, the aluminium behaved in the way expected of a trivalent ion, while the hydrogen behaved as a monovalent ion.

The behaviour of hydrogen ions has been the subject of special study. Experiments with soil from the unmanured Plot 3 (unlimed) show a nearly constant ratio of hydrogen ion concentration to the square root, the calcium ion concentrations ranging from 40 millinormal to 0·1 millinormal. In the course of these experiments several factors that disturb pH measurements on soil and similar materials have been recognised and brought under control.

When a sufficient degree of control can be secured it will be possible to determine the concentration at which the ratio law begins to fail. This should be higher the higher the density of electric charges on the soil. We already have general evidence to support this expectation, but more work is needed to establish the matter beyond doubt.

Conclusion

The presence of electric charges on soil particles could be inferred from the early observations mentioned at the beginning of this review. Yet it was only through the work recently carried out in this laboratory that the net amount of charge on soil particles has been measured with reasonable precision over an extended range of pH. The study of the effects produced by these charges has been facilitated by an extension of Gouy's theory which has been checked experimentally in several ways. In this way a number of new lines of investigation have been opened up.

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REVIEW OF WORK ON POTATO VIRUS DISEASES

Work on potato virus diseases was started in 1940 with the appointment to the department of Mr. J. P. Doncaster and Dr. P. H. Gregory, as Officers of the Agricultural Research Council, to study the spread of potato virus diseases in the ware-growing districts of eastern England. It was known that the rapid degeneration of potato stocks in such districts occurs because of increasing infection with the aphis-transmitted viruses that cause leaf roll and rugose mosaic, but there was no information on factors affecting the rate at which these spread.

In seed-producing districts correlations have been found between aphis infestations and the spread of leaf roll, and the usefulness of such practices as roguing and early lifting in maintaining the health of stocks is well established. In ware-growing districts, however, there have been few tests of the practicability of such control measures, and there was no information about the relative importance of different sources of infection, the distance over which spread takes place, or the time at which it occurs. The peach aphis, *Myzus persicae*, was generally assumed to be the most important vector, but the relative importance of different aphides was uncertain and knowledge of their life histories was incomplete. There was little or no information about the course of aphis infestations, the time at which they occur and the populations reached, or about the variations in infestation from field to field, district to district, and season to season, and whether such variations are directly correlated with spread of virus diseases. The relative importance of leaf roll and rugose mosaic was uncertain, and few data existed to show whether roguing or isolation from diseased stocks would suffice to prolong the useful life of seed stocks.

An epidemiological study of the two diseases was started in an attempt to remedy such defects in our knowledge. Experiments on a standard plan were made annually in different parts of the country and repeated records were made on selected crops in East Anglia to provide information on the activities of aphides and the spread of viruses. The work also had an immediately practical aim; in 1940 there was need to increase the potato acreage and it seemed likely that to do this seed-sized tubers from ware crops would have to be planted. Hence information was urgently needed on any factors that might be useful in assessing the suitability of stocks for seed. Actually the recognised seed-growing districts increased production enough to supply the need, and there is little doubt that, in spite of the cost of new seed to the ware grower, the separation of potato crops for seed and ware is the most effective and economic method of controlling virus diseases.

During the course of the field work many problems arose that required detailed study in the glasshouse and laboratory. Many of these came from difficulties encountered in attempting to diagnose causative viruses from symptoms. This work disclosed many new strains of virus X, some of which produced symptoms in potatoes readily confused with rugose mosaic; it also showed that

some viruses previously regarded as distinct are strains of the almost ubiquitous virus X (Bawden and Sheffield, 1944). Other variations in the severity of symptoms of plants with rugose mosaic led to the discovery that potato virus Y is not a single, stable virus as generally believed, but occurs in the field in many strains of different virulence causing first-year symptoms in the variety Majestic that vary from a faint mosaic to severe leaf-drop streak. The common strains are all aphis-transmitted, but one strain, previously thought to be a separate virus and called virus C, was not transmitted by any of the tested aphides. Several new aphides were identified as vectors of virus Y; some of these, e.g., *Aphis rhamni*, are in glasshouse experiments as effective vectors as *M. persicae*, but field observations suggest that they are of little importance as natural vectors (Kassanis, 1942; Bawden and Kassanis, 1947). Experiments with different potato varieties showed that these not only differ in the symptoms produced by virus Y, but also in their susceptibility to infection, in the concentration of virus reached in their sap, and in their efficiency as sources of infection for aphides. It was shown that glasshouse tests needing few tubers could reliably be used for assessing performance in the field. Resistance to infection with virus Y was independent of resistance to leaf roll, and the differences found between different varieties were amply sufficient to account for the facts that different varieties degenerate at different rates and because of infection with different viruses (Bawden and Kassanis, 1946).

The diagnosis of leaf roll is also far from easy, for individual plants are dwarfed to varying extents and causes other than virus infection may make the leaves roll. Part of the differences in the severity of reaction of individual plants to leaf roll virus undoubtedly arise because the plants contain strains of virus X of different virulence, but there is evidence, though as yet inconclusive, that leaf roll virus, like virus Y, occurs in a range of strains differing from one another in virulence. Phloem necrosis was found useful for differentiating between true leaf roll from leaf rolling produced by other causes; with the virus disease, necrosis was invariably present at the base of the stem but was not found in other plants (Sheffield, 1943).

Aphis investigations

Four species of aphides occur regularly in potatoes in eastern England, *Myzus persicae* (Sulz.), *Aphis rhamni* Fonsc., *Macrosiphum solanifolii* (Ashm.), and *Aulacorthum solani* (Kalt.). The infestations of these aphides vary widely from season to season; *M. solanifolii* and *A. solani* occurred in large numbers only in 1945 and there is no reason to believe these two species are important in spreading rugose mosaic and leaf roll. *A. rhamni* also seems to be unimportant compared with *M. persicae*, possibly because it is less active and moves less freely from plant to plant. Heavy infestations of *A. rhamni* occurred in 1940, 1941 and 1942; the species was rare between 1943 and 1946, but became abundant again in 1947. Its only method of overwintering seems to be in the egg stage on species of *Rhamnus* from which migrants pass to potatoes in June

or early July; infestation on potatoes are usually maximal in August (Doncaster, 1943).

Fruiting peaches out of doors and in unheated glasshouses were the most important hosts on which *M. persicae* overwintered as eggs. This species, however, has alternative methods of overwintering, though the success of these depends greatly on the weather. During mild winters the aphid can continue to survive on brassica crops, sugar beet stecklings and other winter-hardy herbaceous plants. After the severe winters of 1940–1, 1941–2, 1944–5 and 1945–6, few *M. persicae* survived by this manner, and migrations from peach were also smaller and later than usual, so that infestations on potatoes developed later than in other years. Another overwintering site for *M. persicae* was discovered in mangold clamps. Aphides introduced on the leaves survive and multiply provided the clamp covering is adequate to prevent damage to the roots by frost (Broadbent, 1947).

The spring migration of *M. persicae* from overwintering sites to potatoes took place each year during May, and sometimes continued into June, a period when early potatoes are well advanced and main crops just above ground. The maximum population on the foliage was usually reached towards the end of July. The numbers then declined (because of migration to other hosts and the activities of parasites and predators), reached a minimum during the first half of August, and sometimes showed a second but smaller rise in September. In 1941 the population did not reach its maximum until about the end of August, and this was associated with unusually late spread of leaf-roll in potato crops.

There was more spread of both leaf roll and rugose mosaic in years of heavy infestations of *M. persicae* than in others, but there was no simple quantitative relationship between aphis numbers on different crops and the spread of virus diseases. Often there was a greater spread in crops with light than with heavy infestations, suggesting that the activities of individual aphides are more important than the populations achieved. Only aphides that move from plant to plant can transmit viruses, and it seems that conditions within the crop that influence their movement, particularly in early stages of crop growth, are more important than the size of the population reached later in the season. Apterae may do some transmission at or near the peak of infestation, especially in dense crops where interlacing of the foliage facilitates movement from plant to plant, but the winged spring migrants seem to cause much of the total spread (Gregory, 1943). The winged migrants bred on potatoes seem to be relatively unimportant, perhaps because they are no longer attracted by potatoes or because the plants are now more resistant to infection.

The aphis populations were estimated by counts at regular intervals of the numbers occurring on 100 leaves taken from plants selected at random. Information on the number and movement of winged migrants was obtained by catches on specially designed sticky traps. The lack of any quantitative agreement between trap catches or counts of aphis populations on the plants and the amount of spread of virus diseases suggested that the method might be unreliable. The efficiency of the counting method and of the sticky traps was therefore tested thoroughly. It was concluded

that an estimate of the aphides per plant is more useful in virus work than one per 100 leaves, for the number of leaves per plant varies greatly during the season and from crop to crop, and the individual plant is the unit concerned in infection. A rapid and reasonably accurate method of estimating the aphis population per plant was devised based on the percentage of leaves infested and not calling for counts of individual aphides.

Sticky traps were found to give reproducible results when placed at the same height in different parts of the same potato crop. Hence the catch of a single species or total catches in different localities or in different seasons can be legitimately compared. Yellow traps caught more aphides than did white ones. Different species fly at different heights during the summer migration, so that traps at one height only are unsuitable for estimating the relative abundance of different species.

The conditions influencing flight of winged aphides are still far from understood. Field observations and preliminary laboratory experiments suggested that high humidity is less effective in preventing flight than was generally believed. Also, records of wind speeds taken within and above potato crops showed that wind speeds within the crop are often suitable for flight when meteorological instruments in more normal positions would suggest a too strong wind.

The spread and control of leaf roll and rugose mosaic

Periodical sampling of 63 crops of Majestic showed that on the average three-quarters of the final yield of tubers was obtained by the middle of August. In the wet summers of 1941 and 1944, however, about a quarter of the final yield was added in September. The weight of "seed" size tubers averaged 4·1 tons per acre at its maximum in July or August, and declined to 3·2 tons at the end of the season. Tubers are formed during July and subsequent differences in the rate of growth of individual tubers leads to their differentiation into "ware", "seed" and "chats". The yield of seed sized tubers per acre can be increased by close spacing and by planting large setts, but the total increased yield of all tubers obtained by these practices does not usually exceed the increased weight planted. Wide spacing of small setts gives the highest yields of seed and of total tubers per ton of potatoes planted, but close spacing of large setts gives the highest yields per acre. Under present conditions in the ware-producing districts it is more profitable to allow a crop to mature at normal spacing than to attempt by early lifting, or by close spacing, to increase the proportion of seed.

Information on the times and distances of spread of rugose mosaic and leaf roll was obtained by standardised trials made each year at a number of centres. In high-land seed-growing districts, such as North Wales, Dartmoor and Northumberland, the diseases increased little in any year, but the amount of spread in lowland districts varied greatly. It was least in 1942 when *M. persicae* was scarce on all hosts. The two diseases spread at different rates in different districts, the increase of rugose mosaic varying from one-quarter to nearly six times that of leaf roll. Most infections

occurred early in the season; about half the season's spread of both viruses normally occurred by the time the aphis population reached its peak. Rugose mosaic increased after the first week in August in only 10 per cent. of the crops and leaf roll in 30 per cent. Burning of haulm, or lifting early enough to avoid virus infection of the tubers, would therefore involve very substantial losses of crop. Spread of virus is mainly local, and distant stocks of infected potatoes are relatively harmless to healthy stocks, except perhaps to the edge rows. The most important sources of virus are infected plants scattered within the crop, that is infected tubers in the stock planted or volunteer plants surviving from previous crops. Volunteer plants were found to be unexpectedly numerous and their existence points to the value of a good rotation in safeguarding the health of stocks. In the years 1944–46, from 2,000 to 7,000 volunteer plants to the acre were found in the first crop after potatoes. In the third year, the average interval before another potato crop was taken on the same land, there was an average population of 700 volunteers. The health of these volunteers was roughly the same as that of the crop from which they came, for leaf roll and rugose mosaic do not appear to spread between volunteer plants growing in other crops. In agreement with this, no aphides were found infesting volunteer potato plants in cereals. Volunteers from badly infected potato crops, however, are common sources of infection and are often responsible for the rapid degeneration of high quality stocks (Doncaster and Gregory, 1948).

Removing obviously infected diseased plants from Majestic stocks during July did not appreciably reduce the spread of either rugose mosaic or leaf-roll. Roguing in mid-June, tested in one season only, reduced rugose mosaic to one-third of the amount in unrogued plots, but had no effect on the spread of leaf-roll. Roguing presumably fails to control spread because of the early date at which most transmission occurs. If roguing were repeated and plants showing symptoms of current season infection were also removed, the percentage of diseased tubers could be halved; further improvement in health would result from removing the plants adjacent to those showing symptoms, but roguing on this scale is uneconomic.

The amount of transmission by early winged migrants in all probability also explains the failure of fumigating large plots with nicotine vapour to maintain the health of potato stocks. Tests in 1942, 1943 and 1944 showed that one fumigation successfully destroyed the aphis infestation but had little effect on the spread of rugose mosaic and leaf-roll.

The results of these field studies and experiments suggests that healthy potato seed could if necessary be produced in the English lowlands, but this would call for drastic roguing and such early lifting that it would be uneconomic. The most practical method of increasing the useful length of life of stocks seems to be the further improvement of health in seed-growing districts, so that fewer infected tubers are planted in the ware crops, which themselves should be grown away from infected stocks and, most important, on land free from volunteers.

Potato virus X

Improvement of seed stocks requires more than the still further reduction of leaf roll and rugose mosaic and needs extending to the control of mild mosaic caused by potato virus X. This virus is almost universally present in commercial stocks of many varieties, and though its effects on individual plants are small compared with those of the aphis-transmitted viruses, the aggregate losses it causes probably exceed those caused by the others combined. Yield trials with Majestic and Arran Banner (Bawden, Kassanis and Roberts, 1948) showed that infection with different strains of virus X reduced the yield by from 5 to 25 per cent., so that with present potato acreage the annual loss in Majestic alone is probably the equivalent of the produce from 50,000 acres.

Control is being attempted by the establishment of new virus-free stocks of these varieties, which necessitates first the selection of individual tubers and their subsequent propagation to large quantities. Rapid and reliable methods of testing for avirulent strains, applicable to tubers as well as growing plants, have been devised, but evidence was also obtained that selection of new lines needs basing on features additional to freedom from infection. The progeny of different tubers of one variety may vary in yield and other cultural qualities, even though they are virus-free.

Field experiments showed that virus X spread slowly at Rothamsted compared with leaf roll and rugose mosaic. Spread occurred only to healthy plants in direct contact with infected ones. Some strains spread more rapidly than others, but less than 1 in 10 of the healthy plants in contact with infected ones during one growing season became infected. Spread was much more rapid in tomato plants than in potatoes, and in tomatoes spread was demonstrated between plants having only root contact with one another. Underground spread also probably occurs with potatoes, for this is the simplest explanation of the occurrence of infected tubers from plants where foliage is apparently virus-free at the end of the season (Roberts, 1946; 1948). Spread can also occur as a result of contact between the sprouts of healthy and infected tubers, but other parts of the tuber are difficult to infect.

It is concluded that the propagation of virus-free stocks on a commercial scale is possible provided strict precautions are taken to exclude sources of infection, of which the most important are likely to be volunteer plants.

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12. Sheffield, F. M. L. 1943. Ann. Appl. Biol., **30**, 131–36.

PUBLICATIONS

Department of Physics

1. PENMAN, H. L. 1948. *Natural evaporation from open water, bare soil and grass.* Proc. Roy. Soc., **A., 193,** 120-145.

Two theoretical approaches to evaporation from saturated surfaces are outlined, the first being on an aerodynamic basis in which evaporation is regarded as due to turbulent transport of vapour by a process of eddy diffusion, and the second being on an energy basis in which evaporation is regarded as one of the ways of degrading incoming radiation. Neither approach is new, but a combination is suggested that eliminates the parameter measured with most difficulty—surface temperature—and provides for the first time an opportunity to make theoretical estimates of evaporation rates from standard meteorological data, estimates that can be retrospective.

Experimental work to test these theories shows that the aerodynamic approach is not adequate and an empirical expression, previously obtained in America, is a better description of evaporation from open water. The energy balance is found to be quite successful. Evaporation rates from wet bare soil and from turf with an adequate supply of water are obtained as fractions of that from open water, the fraction for turf showing a seasonal change attributed to the annual cycle of length of daylight. Finally, the experimental results are applied to data published elsewhere and it is shown that a satisfactory account can be given of open water evaporation at four widely spaced sites in America and Europe, the results for bare soil receive a reasonable check in India, and application of the results for turf shows good agreement with estimates of evaporation from catchment areas in the British Isles.

2. PENMAN, H. L. 1949. *The dependence of transpiration on weather and soil conditions.* J. Soil Sci., **1,** 74-89.

The evaporation from an open-water surface can be estimated from weather data; the ratio of the transpiration from plentifully watered turf to the evaporation from similarly exposed open water is known as a function of time of year. These results of earlier work are re-stated and used as a basis for estimating transpiration rates when optimum water supply is not maintained. It is assumed that the roots occupy a depth of soil which will yield a definite amount of water at maximum rate. After this amount is transpired the rate is limited by the ability of the lower soil to transmit water, and on the basis of earlier experimental work a composite drying curve is drawn up. With this curve and the relevant weather data it is possible to estimate the seasonal changes in the moisture content of soil under turf. It is shown that the times of the running of the field drains at Cambridge University Farm can be predicted using only one arbitrary constant—the available water in the root zone—which varies from year to year with the spring rainfall. No other collection of records is as satisfactory for testing purposes, but applications to drain gauge records from Craibstone (Aberdeen), Harrogate, Compton and Farlington have given generally satisfactory results. The survey shows the great desirability of wider studies of root development as affected by soil type and depth, fertiliser treatment and weather conditions.

3. SCHOFIELD, R. K., and PENMAN, H. L. 194 . *The concept of soil moisture deficit.* Proc. 2nd Int. Conf. on Soil Mechanics and Foundation Engineering, Rotterdam, June, 1948. (In the press.)

A study of the records of the Rothamsted drain gauges shows how soil moisture deficits develop in bare soil.

A measure of soil moisture deficits under grass and other crops can only be obtained by determining moisture percentages when the soil is very uniform and has the kind of structure that gives a rapid die-away of drainage. A way of reducing the disturbance caused by soil irregularity has been explored at Rothamsted.

Observations at Rothamsted show that evaporation from grass plentifully supplied with water is nearly the same as that from an equal area of open water and shows essentially the same dependence on weather.

An estimate of the mean annual evaporation from a grassed drain gauge, that is scarcely ever short of water, has been made from evaporimeter records. This agrees well with the observed annual excess of rainfall over drainage.

Assuming that evaporation from the grass of the Cambridge University Farm is checked when the soil moisture reaches a value, C (which varies

slightly from one year to another), values for the soil moisture deficit have been estimated that correctly predict the time when drainage re-starts.

Typical values for C and for the maximum soil moisture deficits found at a number of sites in selected years have been tabulated.

It is not possible to determine uniquely the condition of zero soil moisture deficit in sandy soils with a deep water table.

4. Schofield, R. K. 1947. *Some problems connected with the retention of ions by clay constituents.* Clay Minerals Bull. No. 1, 16–18.

After repeated washing of a sample of a clay subsoil with N/5 ammonium chloride solution, adjusted by the addition of hydrochloric acid or ammonia to the required pH, the net negative charge was found by the excess of ammonium ions over chloride ions displaced by subsequent washing with potassium nitrate solution. At pH values between 2·5 and 5 a small retention of chloride ions which diminishes and ultimately vanishes with rise in pH shows that a small number of positive charges are present. A treatment with acid ammonium oxalate in sunlight dissolves some 5 per cent. of iron oxide and removes the positive charges. The residue contains the clay mineral with unimpaired base exchange power. This has a constant negative charge between pH 2·5 and pH 5 which is presumably due to isomorphous replacement. Above pH 5 the negative charge increases, no doubt due in the main to the dissociation of hydrions from hydroxyl groups attached to silicon.

5. Schofield, R. K. 1947. *Calculation of surface areas from measurements of negative adsorption.* Nature, **160,** 408.

A simple formula is given which relates the negative adsorption of ions per unit area of phase boundary carrying a large surface charge to the valencies and concentrations of the ions in solution. When the negative adsorption per unit weight of clay, or other sorbate, has been measured at a series of electrolyte concentrations the formula permits the calculation of the area of phase boundary. Applied to data for bentonite this method gave an area 450 square metres per gram. The theoretical maximum for pure montmorillonite is 800 square metres per gram.

A sample of jute carrying a high surface density of carboxyl groups was found to have an internal area of 160 square metres per gram, which is about one thousand times the external area of the fibres. There was an internal volume of 0·7 c.c. per gram, which evidently consists of passages of the order of 100 A in width. A sample of jute carrying a low surface density of carboxyl groups gave values almost equal to those that would be calculated from Donnan's equation for the membrane equilibrium.

6. Schofield, R. K. 194 . *A ratio law governing the equilibrium of cations in the soil solution.* Proc. Eleventh Int. Congress of Pure and App. Chem. (In the press.)

A ratio law applicable to the equilibrium between the exchangeable cations and those in solution has been verified over a limited range of concentration for potassium, magnesium, calcium, aluminium and hydrogen ions for soil samples from the Rothamsted Park Grass Plots. The law is not obeyed by hydrogen ions in the case of a soil from Natal which carries positive and negative charges in nearly equal amounts.

7. Russell, E. W. 194 . *The determination of volume weight and air space of stony soils.* Proc. 2nd Int. Conf. on Soil Mechanics and Foundation Engineering, Rotterdam, June, 1948. (In the press.)

There are a number of reasonably good methods available for determining the volume weight and the volume of voids, or the air space, in stone-free soils if they are soft enough or moist enough to allow a sample of predetermined volume being taken with a suitably designed sampling tube or cylinder. These methods, however, fail, or become very inaccurate, for soils containing even quite small proportions of stones, for the sampling tube is bound to affect the packing of the soil inside the tube if the cutting edge meets a stone of appreciable size. For such soils it is preferable to take an undisturbed sample of soil, of irregular shape and unknown volume, and determine its volume after sampling. This can be easily done for very porous non-cohesive soils, such as gravels and coarse sands, by fixing the soil in a cement before removing the sample, as for example by pouring molten paraffin wax on to it and cutting out the block of impregnated soil.

There are usually no fundamental difficulties in taking an undisturbed sample of a cohesive soil, and the problem of determining its volume weight

and volume of air form the subject of this paper. Volume weights can obviously be determined if the method developed involves displacing all the air by a liquid that is immiscible with water and then determining the volume of this impregnated sample by weighing it in the same liquid that has been used for impregnation. It is shown that this method is applicable to moist or dry soils, and that no elaborate apparatus is needed if only a volume weight is required, although a vacuum pump is essential if the volume of the air spaces is also required.

The principle of the method used is to weigh the sample in air, to impregnate it with a non-volatile water-insoluble oil of low viscosity, and weigh it in this oil, then to weigh the impregnated sample in air again when it is fully drained. From these weighings the volume of the sample and of the air space it contains can readily be calculated.

The points of technique discussed refer to the type of oil to be used, and it is shown that lamp paraffin (kerosene) can be made suitable; the method of replacing the air by this oil so that a minimum quantity of water from the moist sample is lost at the same time; and draining the excess liquid from the impregnated clod. If a moisture determination is made on the sample after these determinations have been made, the density of the soil particles themselves can be calculated, and this determination can often serve as a check on the accuracy of the whole procedure.

OTHER PAPERS

8. KEEN, B. A. 1947. *Middle East in transition.* Future, **2,** 37–46.
An article based on the author's report "*The agricultural development of the Middle East*". (See paper No. **3** of the 1946 report.)

9. RUSSELL, E. W. 1946. *Modern ideas on potato cultivation.* Agric. Prog., **21,** 103–104.

10. PENMAN, H. L. 1947. *Future developments in agricultural meteorology.* Weather, **2,** 137–141.

11. SCHOFIELD, R. K., and RUSSELL, E. W. 1948. *The significance of particle size in relation to soils.* Conference on Particle Size Analysis organised by the Institution of Chemical Engineers, February, 1947.

12. RUSSELL, E. W. 1947. *Problems of soil and land classification.* Nature, **160,** 686–687.

Department of Chemistry

13. CROWTHER, E. M. 1947. *Fertiliser experiments in colonial agriculture.* Memoranda on Colonial Fertiliser Experiments, 10–28, H.M. Stationery Office, Colonial 214.

The Colonial Advisory Council of Agriculture, Animal Health and Forestry recommended that steps should be taken to carry out in Colonial territories fertiliser experiments with different crops on all soil types and through the sequence of cropping, with the object of obtaining precise information on the responses of crops to the different fertilisers, the economics of application, the use of any local fertiliser materials available and the role of trace elements. This memorandum sets out the general principles of experimental design and discusses their application to some of the more pressing problems in colonial agriculture. Special attention is given to factorial designs in which high-order interactions are confounded with blocks and to fractional replication. A convenient notation is given for working out the arrangement of blocks in such experiments. It is shown how complex experiments at a few centres can be supplemented by series of simple experiments, even of a purely observational nature, on large numbers of individual holdings. It is urged that the early trials in any area should be made with standard fertilisers and that local fertiliser material should be used in field trials only where they can be compared against standard fertilisers.

14. CROWTHER, E. M. 1948. *Fertilisers in the agricultural expansion programme.* Agriculture, **55,** 491-500.

The use of fertilisers in England and Wales in 1948 and the next few seasons is reviewed in relation to the vast agricultural expansion programme and the fertiliser supplies likely to become available. A provisional fertiliser programme is drawn up, and attention is directed to a number of ways in which the use of fertilisers must be improved if the wartime efficiency in crop production is to be surpassed or even maintained.

15. Crowther, E. M. 1947. *The use of salt for sugar beet.* British Sugar Beet Review, **16,** 19–22.

A summary of the results of recent field experiments.

16. Crowther, E. M. 1947. *Soils and fertilisers.* J. Royal Agric. Soc., **108.**

17. Hale, J. B. 1947. *Mineral composition of leaflets in relation to the chlorosis and bronzing of oil palms in West Africa.* J. Agric. Sci., **37,** 236–244.

Some disorders causing chlorosis and necrosis of the foliage of oil palms from three West African estates have been investigated by spectrochemical analysis of the dry leaflets for potassium, calcium, magnesium and manganese.

Statistical examination of the chemical analyses of leaflets from fronds of different ages and from different positions along the frond, shows that it is important to sample and analyse separately at least upper, middle and lower fronds from each tree. Little is gained by analysing separately samples from different positions along the length of the frond.

The "bronzing" diseases are tentatively ascribed to deficiency of potassium. One palm is probably a case of combined magnesium and potassium deficiency. One disease, "lemon frond", cannot be attributed to a deficiency of any of the elements determined.

The differences in mineral composition of the leaflets between palms from the three estates are greater than those due to the diseases, and a further survey is proposed to determine the range of variation of composition of healthy trees and the levels below which deficiencies set in.

18. Rickson, B. 1948. *A semi-micro combustion method for the determination of organic carbon.* Analyst, **73,** 268-274.

Department of Pedology

19. MacEwan, D. M. C. 1946. *The investigation of soil clays by X-rays.* Chem. Indust., No. 36.

A brief account of present-day techniques.

20. MacEwan, D. M. C. 1947. *The nomenclature of the halloysite minerals.* Min. Mag., **28,** 36–44.

A historical account of the name "halloysite" and an argument against the proposed new name "endellite". It is argued that the name "halloysite" was originally applied to the same material for which the new name is now proposed, i.e., the material with two extra molecules of water over the kaolinite formula, and that its application to the less hydrous form is a recent innovation. It is suggested that the name "halloysite" be used more generally to include both forms.

21. MacEwan, D. M. C. 1948. *Les mineraux argileux de quelques sols ecossais.* Verre et Silicates Industriels.

An account of a mineralogical investigation by X-ray and chemical methods (the latter carried out by A. Muir) on the clays of three Scottish podzols derived from schists. Emphasis is laid on the importance of studying the clay mineralogy of the whole profile, as a means of tracing the processes of alteration.

The main points are: In the lowest horizons the minerals are essentially those of the parent rock (chlorites, biotite, muscovite), except that felspars are absent, and kaolinite is present (this constituent persists in about the same proportion throughout the profile). In the intermediate layer, biotite is replaced by hydrobiotitic material, and oxides of iron and aluminium appear (crystalline in one soil, amorphous or microcrystalline in the other two). Towards the surface chlorites and oxides disappear, biotitic material becomes less plentiful or disappears, and the main constituents are kaolinite and "illite"; the last-named may be found by hydration of the muscovite-like material.

22. Goldschmidt, V. M., and Muir, A. 1947. *Geochemistry of minerals.* Thorpe's Dictionary of Applied Chemistry, Vol. 7.

Department of Soil Microbiology

23. Erickson, Dagny. 1947. *Differentiation of the vegetative and sporogenous phases of the actinomycetes. 1. The lipid nature of the outer wall of the aerial mycelium.* Journal General Microbiology, Vol. 1, No. 1, 39–44.

The characteristic dry powdery appearance of the aerial mycelium of actinomycetes and the difficulty of wetting the constituent spores appear to be due to lipid substances in their outer walls. These substances are removed

by fat solvents, and wetting agents, destroyed by alkali and are probably glyceride in nature. A staining with Sudan IV in ethanol clearly distinguishes the lipid-containing aerial mycelium from the vegetative mycelium.

24. Erickson, Dagny. 1947. *Differentiation of the vegetative and sporogenous phases of the actinomycetes.* 2. *Factors affecting the development of the aerial mycelium.* Journal General Microbiology, Vol. 1, No. 1, 45–52.

When first isolated on soil extract agar, soil actinomycetes consistently produce aerial spores in surface colonies. They retain this property when maintained in sterile soil, or when grown on washed suspensions of common soil bacteria, living or dead, in a water agar medium. In soil, when the composition, moisture content and temperature are kept constant, the initial stimulus towards the production of aerial mycelium is free access of air; the quantity and nature, vegetative or sporogenous, of the inoculum, and, within a broad range, the pH of the soil are of minor importance. Once growth is established, the next most important factor stimulating sporulation in the soil is also physical, namely dehydration. In natural and sterilized soils of different origins, and in a "synthetic" soil containing 250 p.p.m. of nitrogen as nitrate, the modes of growth of different actinomycetes strains are similar, and generally uncharacteristic of their species.

25. Holdsworth, M., and Nutman, P. S. 1947. *Flowering response in a strain of* Orobanche minor *L.* Nature, **160,** 223–224.

The relation between the flowering of the parasitic plant *Orobanche minor* L. and of its host red clover, was examined in experiments in which the sowing date was varied and parasitised plants were grown in different day lengths.

Early sown (January) or moderately late sown (June) Orobanche plants on clover sown in the early spring come into flower at about the same time (August). Delay in the sowing of the host plant (April to June) leads to a delay in the flowering of both host and parasite. Late sown (July onwards) clover and Orobanche both fail to come into flower in the seedling year.

The dependence of flowering in the parasite on the flowering of the host is further shown in their photoperiodic responses. Clover is a long day plant and its flowering can be inhibited by a day length of 11 hours; a treatment which results in a corresponding inhibition of flower formation in the parasite. Alternatively exposure to long day (16½ hours) leads to a simultaneous flowering of both host and parasite independently of sowing date. These results show that both host and parasite are long day plants although the latter being entirely subterranean cannot directly perceive length of day; some influence or substance affecting flower formation—possibly a common flowering hormone—must therefore be transmitted from the host to the parasite.

26. Thornton, H. G. 1947. *The biological interactions of* Rhizobium *to its host legume.* Antonie van Leeuwenhoek, **12,** 85–96. Jubilee Volume, Albert J. Kluyver. (Review.)

27. Oxford, A. E., and Singh, B. N. 1946. *Factors contributing to the bacteriolytic effect of species of myxococci upon viable eubacteria.* Nature, London, **158,** 745.

A strain of *Myxococcus virescens* isolated at Rothamsted produces two substances. One is soluble non-enzymatic antibiotic substance, the other is an exocellular lytic (proteolytic) enzyme which is active against non-viable bacteria only.

28. Singh, B. N. 1947 *Studies on soil acrasieae.* 1. *Distribution of species of* Dictyostelium *in soils of Great Britain and the effect of bacteria on their development.* Journal General Microbiology, **1,** No. 1, 11–21.

A method of isolating species of Dictyosteliaceae from soil and other substrates is described.

Of ninety-three different strains of bacteria tested as food for *Dictyostelium giganteum* and *D. mucoroides,* some were readily or slowly but completely eaten, others were partly eaten and the rest were inedible. No correlation between the edibility of the bacteria and the formation of normal fruiting bodies could be found. More Gram-negative than Gram-positive strains were edible, and non-pigmented bacteria proved more suitable than pigmented bacteria for the normal development of *Dictyostelium spp.*

Values of pH between 4·1 and 8·9 had no effect on the abundance or on the types of fruiting bodies produced in either *D. giganteum* or *D. mucoroides* when suitable strains of bacteria were supplied as food to the myxamoebae on non-nutrient sugar.

The maximum dimensions and the form of sorocarps and occasionally the colour of the sori were influenced by the type of bacteria used as food supplies. The influence of the bacterial food supply on the classification of Acrasieae is discussed and one new species (*D. giganteum*) is described.

Species of *Dictyostelium* are frequently present in arable soils in Great Britain. The common occurrence of *Dictyostelium spp.* in soils, which have been unmanured or treated with artificial fertilisers only for 100 years or more, disproves the belief that *Dictyostelium spp.* are dung organisms.

29. Singh, B. N. 1947. *Studies on soil acrasieae. 2. The active life of species of* Dictyostelium *in soil and the influence thereon of soil moisture and bacterial food.* Journal General Microbiology, **1**, No. 3, 361–367.

When spores of *Dictyostelium mucoroides* or *D. giganteum* were added to sterilized soil containing a pure culture of an edible bacterium, the resulting myxamoebae actively destroyed the bacteria in the soil. When spores of *D. mucoroides* were added to the centre of a Petri dish of sterilized soil containing bacterial food no fruiting bodies were formed at a moisture content of 15 per cent. or less. At 19 per cent. moisture fruiting bodies were formed at the centre only. At 33 per cent. moisture the central area over which fruiting bodies appeared steadily increased in size until it covered the whole soil surface. Species of *Dictyostelium* can also pass through the life cycle in fresh unsterilized soil.

The nature of the bacterial food supply affects the growth of species of *Dictyostelium* in soil as measured by fruiting body formation. Normal fructification occurs on soil containing certain bacterial strains which induce abnormal fructification on agar.

30. Singh, B. N. 1947. *Myxobacteria in soils and composts; their distribution, number and lytic action on bacteria.* Journal General Microbiology, **1**, No. 1, 1–10.

Myxococcus virescens, *M. fulvus*, *Chondrococcus exiguus* and *Archangium sp.* are widely distributed in the soils of Great Britain including some treated only with artificial fertilisers. *Myxococcus virescens* and *Chondrococcus exiguus* appear to be the dominant species. The numbers of myxobacteria ranged from 2,000 to 76,400/g. of soil. In an actively decomposing compost of sludge and straw the number of *Myxococcus fulvus* was found to be over 500,000/g.; *M. virescens* and *Chondrococcus exiguus* were also present, but less abundantly.

Variation of pH between 4·0 and 8·8 does not affect the growth of *Myxococcus fulvus*, *M. virescens* and *Chondrococcus exiguus*, and normal fruiting bodies were produced in the presence of suitable bacteria. *Myxococcus fulvus* and *M. virescens* do not attack filter paper.

Both Gram-positive and Gram-negative bacteria growing on solid media may be lysed by extracellular secretions of *M. virescens*, *M. fulvus* and *Choncrococcus exiguus*. Of forty-seven Gram-positive and forty-seven Gram-negative strains of bacteria tested with three species of myxobacteria, a higher percentage of Gram-negative than of Gram-positive strains was attacked. Pigmented strains of bacteria are more resistant to the lytic action of myxobacteria than the non-pigmented strains. Different species of myxobacteria and different strains of the same species differ in their lytic action on a number of species of bacteria.

The extracellular lytic substance produced by *Myxococcus virescens* passes through a cellophan membrane. A method of growing *M. fulvus* and *M. virescens* in mass cultures in liquid media to produce extracellular lytic secretions is described.

Department of Botany

BOOK

31. Long, H. C., and Brenchley, W. E. 1947. *Suppression of weeds by fertilisers and chemicals.* 2nd edition. pp. 87.

SCIENTIFIC AND TECHNICAL PAPERS

32. Brenchley, W. E. 1947. *The toxic action of molybdenum in relation to soils and crops.* Ann. Appl. Biol., **35**, 139-160.

Attention has hitherto been focused on the harmful effect of molybdenum on animals, and there is comparatively little knowledge of the conditions in which molybdenum is poisonous to plants. There is evidence in the literature

that there are obvious differences in response to molybdenum poisoning in different soils, but no adequate reason has been put forward.

Tomatoes grown in ordinary loam showed little outward sign of poisoning with heavy doses of sodium molybdate, but some depression of crop occasionally occurred, especially when the dose was divided into early and late treatments. The response varied with season and variety. On certain light and fen soils the plants were killed at an early stage with the heavier dressing of molybdate, and seriously injured with the lighter dose, the leaves showing the golden colour characteristic of molybdenum poisoning in various plants.

The reaction of different crops varied considerably in the same soil with similar treatments. On old cucumber soil tomatoes showed no sign of toxicity even with the heavy dressing, flax was progressively damaged with increasing doses, while *Solanum nodiflorum* was most seriously affected even with the lighter dressing of molybdate. It was impossible to predict the reaction between soil, poison and crop without actual experiment.

The growth of flax was greatly impeded on a manganese deficient fen soil, and the molybdenum toxicity was masked in consequence. When the deficiency was corrected the poisonous effect of molybdenum on this soil was very marked, even with the lower dressing.

33. Warington, K. 1947. *Molybdenum and its effect on growth of lettuce.* Victory Farm Forum, No. 27.

Lettuce grown in nutrient solution showed such marked benefit from the addition of 0·1 p.p.m. molybdenum that the element appears to be essential for normal healthy growth. In its absence the plants remained small and pale and developed a frill of withered leaves between the healthy inner and outer whorls. Excess molybdenum was harmful and 100 p.p.m. of the element caused serious injury. The poisonous effect was to some extent dependent on the variety of lettuce and the time of year at which it was grown, but no correlation between the molybdenum requirement of the plant and season was found.

34. Brenchley, W. E. 1947. *The essential nature of certain minor elements for plant nutrition. II.* Bot. Rev., **13**, 169–193.

A review of the literature of minor elements in their relation to plants, following two similar reviews published in 1935 (Bot. Rev.) and 1943 (Biol. Rev.).

35. Brenchley, W. E., and Thurston, J. M. 1948. *Suggestions for the control of wild oats.* Agriculture, **51**, 12-16.

Information about methods that have been tried for the control of wild oats has been collected during the last year from various parts of the country, and the results are here summarized. Suggestions are also made for field experiments involving control by special methods of cultivation and cropping.

36. Brenchley, W. E., and Long, H. C. 1947. *Weeds of cornfields.* New Biology, **2**, 96–115.

A survey of the weeds specially associated with cereal crops and methods of cultural and chemical control.

REVIEWS BY W. E. BRENCHLEY

37. Whyte, R. O. 1946. *Crop production and environment.* pp. 372. Faber and Faber. 25/– net. Agriculture, 1947, **LIV**, 333.

38. Nelson, A. 1946. *Principles of agricultural botany.* pp. 556. T. Nelson & Sons, Ltd. 35/–. Agriculture, 1947, **LIII**, 517.

Department of Crop Physiology

39. Watson, D. J. 1947. *Comparative physiological studies on the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years.* Ann. Bot., N.S., **11**, 41–76.

Determinations of net assimilation rate (NAR) and of leaf area per plant or per metre of drill row were made at intervals throughout the growth of field-crops of wheat, barley, potatoes, mangolds, and sugar-beet at Rothamsted. Data are presented from 15 experiments in 6 years. The experiments included comparisons of varieties of the same crop and of sowings made on different dates.

Net assimilation rate showed similar variation with time in all years, rising during the spring months from very low values in winter to a maximum

at midsummer, and subsequently falling during the late summer and autumn. This time trend is attributed to seasonal change in climatic factors. Deviations from a smooth time trend were found to be correlated with temperature deviations. The relation of NAR to temperature varied in different crops; for example, that of potatoes increased, while that of sugar-beet decreased, with increase in the mean daily temperature range. No significant correlation between NAR and mean daily radiation was detected.

Net assimilation rate measured for the same species over comparable calendar periods was found to vary from year to year. This annual variation may have been due partly to differences between years in climatic conditions, and partly to differences between fields in soil conditions. The existence of a seasonal time trend and of annual variation in NAR is evidence against the hypothesis that, apart from short-period fluctuations, NAR is independent of environmental conditions.

All the species tested were found to differ in NAR, when compared over the same calendar period in the same year. The rate increased in the order: wheat, barley, potatoes, mangolds, sugar-beet. At the extremes the NAR of sugar-beet was about twice that of wheat. Small but significant differences of NAR were also found between varieties of sugar-beet and potatoes, but not of wheat.

The net assimilation rate of sugar-beet was slightly increased by later sowing. This may imply that NAR declines with age, independently of change in external factors, but other explanations are possible. Autumn-sown and spring-sown wheat of the same variety differed little in NAR. These results show that variation of NAR with age plays little if any part in determining seasonal variation.

The leaf area per metre of drill row of wheat began to increase rapidly at about the time of maximum shoot number, reached its maximum in early June during the phase of shoot elongation when the shoots had attained about half their final height, and then decreased to zero at the end of July. The sequence of changes in the leaf area of barley was similar, but occurred later in the year; in contrast with wheat, leaf area and shoot number reached their maxima at about the same date, at the end of June. Potatoes attained their maximum leaf area per plant in August, and like cereals showed a rapid decrease of leaf area in the later stages of growth. The change with time in leaf area per plant of sugar-beet depended on the date of sowing. Early sowings produced their maximum leaf area in September, and subsequently there was a slow fall, but the leaf area of late sowings continued to increase into November.

Differences between years and between varieties in leaf area per plant of sugar-beet were mainly due to variation in leaf size and not in leaf number per plant. This was probably also true of wheat, but in potatoes, variation of leaf number also contributed to determine the differences between varieties in leaf area per plant.

Net assimilation rate was much less variable between years and between varieties of the same species than leaf area. Consequently the differences between years and varieties in yield of dry matter reflected mainly the differences in leaf area, and showed no close relation to the much smaller differences in NAR. Similarly, differences between species in yield of dry matter were accounted for almost completely by differences in leaf area, in spite of the wide variation in NAR between species. The reason is that in different species the production of leaf area occurred at different stages of the seasonal cycle of NAR. In general, variation in leaf area was the main factor determining differences in yield; variation in NAR was of minor importance.

40. Watson, D. J. 1947. *Comparative physiological studies on the growth of field crops. II The effect of varying nutrient supply on net assimilation rate and leaf area.* Ann. Bot., N.S., **11**, 375–407.

Growth analysis was used to investigate the physiological causes of variation in dry-matter yield produced by varied nutrient supply to crops of wheat, barley, and mangolds grown in 1939 on three of the classical field experiments at Rothamsted. In these experiments the same crop has been grown continuously on plots receiving varied annual fertiliser treatments, which have continued unchanged over a long period of years. Severe nutrient deficiency has developed on the plots where nutrients have been withheld, and the range of nutrient supply is consequently very wide. The experiments provide information on the effects of nitrogen in the form of sulphate of ammonia,

phosphate, potash, a mixture of sodium and magnesium salts, farmyard manure, and of fallowing during the previous year.

Nitrogenous fertiliser consistently increased net assimilation rate (NAR). This effect was not restricted to the later stages of growth, and consequently cannot be attributed to delayed senescence of the leaves. In the early stages of growth nitrogen usually produced a greater increase of NAR in the presence of other nutrients than in their absence, but in the mangold experiment the addition of farmyard manure or potash caused a reduction in the esponser to nitrogen.

Fallowing causes an accumulation of nitrate in the soil and, like nitrogen supplied in the form of fertiliser, it increased NAR.

The effects of the other nutrients on NAR were smaller and more variable. Phosphate and potash reduced the NAR of wheat, while sodium and magnesium salts apparently increased it. Up to the time of maximum leaf area, all treatments increased the NAR of barley, and the effect of each was increased by the presence of the others. In the subsequent period the average effects of nitrogen, phosphate, and a combined dressing of potassium, sodium, and magnesium salts were all negative, but the interactions between the nutrients were large, possibly because deterioration of the photosynthetic mechanism was more rapid in the leaves of plants with unbalanced nutrient supply in the senescent phase preceding death of the whole plant. In the mangold experiment, phosphate, potash, and the mixture of sodium and magnesium salts all increased NAR in the period before maximum leaf area. Subsequently, the interactions were large compared with the main effects, as in the barley experiment, but it is doubtful whether this has any connexion with senescence or whether it was merely the result of increased sampling errors. In this period phosphate markedly reduced NAR, while potassium or sodium and magnesium salts increased it, when applied separately, but reduced it when applied together.

All treatments increased leaf area per metre or per plant, but the time at which the effects occurred, and the manner in which they were produced, differed with the different nutrients. In the cereal experiments, nitrogen increased both shoot number per metre and leaf area per shoot, so that its effect on leaf area per metre was apparent throughout the whole growth period. Phosphate increased shoot number, but had little effect on leaf area per shoot, tending to depress it in the later stages, presumably by hastening the death of the leaves. Potassium and sodium, on the other hand, had little effect on shoot number, but increased leaf area per shoot, possibly by prolonging the life of the leaves. Consequently, phosphate produced its greatest effect on leaf area per plant at an earlier stage of growth than potassium or sodium. In the mangold experiment nitrogen increased both leaf number and leaf size, and its effects continued to increase throughout the whole period of growth. The increases of leaf area produced by phosphate, potassium, and sodium were maximal in August and September, later falling to zero in October. Phosphate increased both leaf number and leaf size, but potassium and sodium had no effect on leaf number.

The effects of farmyard manure were similar to those of a fertiliser mixture supplying nitrogen, phosphate, and potash.

In general, the effects of varied nutrient supply were relatively greater on leaf area than on NAR; variation in dry-matter production caused by varying nutrient supply was mainly the result of changes in leaf area, and variation of NAR was of secondary importance. In some conditions, however, potassium and sodium produced a greater percentage increase in NAR than in leaf area. This may imply that potassium has special functions in relation to photosynthesis; if so, it appears that in mangolds these functions can also be fulfilled by sodium.

41. Morton, A. G., and Watson, D. J. *A physiological study of leaf growth.* Ann. Bot. (In the press.)

1. The effect of nitrogen, salt (NaCl), and water supply on leaf growth was investigated in two varieties of sugar beet grown in pot culture.

2. The rate of leaf production by the apical meristem was increased by increasing the external nitrogen supply but was unaffected by salt or water supply.

3. In one variety the number of cells in the individual leaf was increased by higher N and water supply, but decreased by salt. In the other variety water supply had no effect on cell number (N and salt not tested).

4. Cell size varied considerably with water supply and other external conditions but no general conclusions can be drawn from the limited data available.

5. The number of cells in the leaf is greatly reduced when the initials arise in complete darkness, although such leaves are capable of normal cell extension if returned to light soon enough.

6. Effects of the treatments on yield and leaf area were examined. NAR was unaffected by external Nitrogen supply, although there was evidence that it is not independent of internal level of nitrogen.

7. Examination of field material shows that the effect of manurial treatment on cell number and cell size in the leaf varied considerably with different species.

42. CROOK, E. M., and WATSON, D. J. *Studies on the storage of potatoes. I. Changes in composition during storage in clamps.* J. Agric. Sci. (In the press.)

Changes in the percentage of dry matter, sugars, starch and nitrogen present in Arran Banner and Majestic potato tubers during storage in clamps until July were studied in two seasons. In the first season, the ascorbic acid content and the distribution of nitrogen between three fractions (insoluble, soluble coagulable, soluble non-coagulable) were also determined. In the second season, weighed samples of tubers were introduced into the clamps, so that changes in absolute amounts of the different constituents present in the tubers or sprouts could be measured. The effects of removing or retaining the soil cover on the clamps after early April were compared.

Dry matter per cent. of fresh weight in the tubers varied little during the early part of the storage period. After the removal of the soil cover in April, the dry matter content began to rise, but it decreased slightly if the soil was left on the clamp.

In the first season, sucrose and reducing sugars per cent. of dry matter both decreased slowly to a minimum in April, and subsequently there was a rapid rise. In the second season, the sucrose and reducing sugar contents increased between October and March; this was followed by a fall until May and a final rise. Starch per cent. of dry matter tended to fall as the storage period lengthened, but after sprouting began there was a temporary rise. Continuous records of the temperatures in the clamps were available for the second season, and it was shown that the rise and fall of sucrose content between October and May could be accounted for by the sensitivity of the starch, sugar balance to low temperatures, which causes potatoes to sweeten at temperatures below 6°C. The changes in reducing sugar content were less clearly correlated with temperature. The final rise of sugar content was attributed to internal changes associated with senescence.

There was no consistent time-trend in total nitrogen per cent. of dry matter. The insoluble nitrogen fraction was almost constant throughout storage, and the other fractions showed little change until the onset of sprouting, after which the soluble-coagulable fraction decreased and the soluble non-coagulable fraction increased. Ascorbic acid content increased during the early stages of storage to a maximum at about the time when sprouts began to appear, and then fell rapidly to a very low value at the end of the storage period.

The total weight of water present in the tubers declined throughout storage. In the clamp which retained its soil cover, 12 per cent. of the water initially present had been lost by July and 6 per cent. was recovered in the sprouts. Removal of the soil cover in April increased the water loss from the tubers to 27 per cent. and the recovery in the sprouts to 8 per cent.

There was no appreciable change in the total dry matter of the tubers until April, but, by July, 15 per cent. of initial dry matter had been lost, and a third of this was recovered in the sprouts. Removal of the soil cover had little effect on the dry matter changes.

The change with time in fresh weight of the tubers was determined mainly by loss of water. Thus, tubers in the clamp covered throughout storage lost 12 per cent. of their initial fresh weight by July, and of this 9 per cent. was contributed by water loss and 3 per cent. by dry matter loss. Removal of the soil cover doubled the loss of fresh weight, entirely by increasing water loss.

The total nitrogen content of the tubers decreased during storage by 10 per cent. of the initial value, and all the nitrogen loss was recovered in the sprouts.

The total amounts of starch and residual dry matter (total dry matter less starch and sugars) in the tubers did not change appreciably between October and January, but in the following month 20 per cent. of the initial starch disappeared and residual dry matter increased correspondingly. The amount of starch then remained nearly constant until May, but subsequently it decreased rapidly and by July, only 60 per cent. of the initial starch remained in the tubers. Residual dry matter also remained nearly constant between February and April, tending to rise slightly, but in May most of the residual dry matter added in the previous three months was lost, and it was this change that caused the increase in starch as per cent. of dry matter at this time. At the end of the storage period residual dry matter increased again. These changes indicate a steady conversion of starch into some component of residual dry matter, proceeding rapidly during January and February, and then very slowly, possibly because of fall in temperature. With the onset of sprouting the change was temporarily reversed, but at the end of the storage period it was resumed at a more rapid rate. The whole of the loss of dry matter from the tubers during storage was at the expense of starch.

Cooking tests showed no appreciable change in the texture of boiled tubers until April, after which a rapid deterioration set in. This was apparently not directly connected with sprouting.

Department of Statistics

STATISTICAL METHODOLOGY

43. Anscombe, F. J. 1948. *Sampling theory of negative binomial and logarithmic distributions.* Biometrika (In the press.)

(i) *Negative binomial distribution.* Remarks on the maximum-likelihood estimation of parameters. The efficiency of estimates of moment type. Mixtures of negative binomial distributions: the nature of the resulting distribution, a test for heterogeneity in the mean. The estimation of a common exponent k from a series of small samples with varying means. The treatment of field insect-population counts.

(ii) *Logarithmic series.* The error of estimation of the index of diversity α. Mixtures of logarithmic series: the nature of the resulting distribution, and test for heterogeneity in the mean.

(iii) Remarks on the compound binomial distributions corresponding to the above compound Poisson distributions.

(iv) Numerical examples.

44. Anscombe, F. J. 1948. *The transformation of Poisson, binomial and negative binomial data.* Biometrika. (In the press.)

The asymptotic behaviour of a transformation (due to A. H. L. Johnson), $x = \sqrt{(r + \frac{3}{8})}$, of a Poisson variable r is shown. Analogous transformations are devised for binomial and negative binomial variables. Tables are given showing numerically the behaviour of the transformations for small values of the mean.

45. Anscombe, F. J. 1948. *The validity of comparative experiments.* J. R. Statist. Soc. (In the press.)

An account of the logic of experimentation, the topics covered being: the effect of randomization on the analysis of an experiment; precautions other than randomization that can be taken to secure validity; current systems of inductive inference; the extent to which it is possible to draw valid conclusions from an experiment.

46. Quenouille, M. H. 1947. *Notes on the calculation of autocorrelations of linear autoregressive schemes.* Biometrika, **34**, 365–367.

It is shown that the fundamental constants of autoregressive schemes can be calculated by an extension of the method of generating functions whereby inverse linear generating functions are used.

47. Quenouille, M. H. 1948. *Some results in the testing of serial correlation coefficients.* Biometrika, **35**. (In the press.)

It is demonstrated mathematically that the serial correlation coefficients can with certain modifications be tested by the transformation used for the ordinary correlation coefficient. This result is tested numerically.

48. Quenouille, M. H. 1948. *A large-sample test for the goodness of fit of autoregressive schemes.* J. R. Statist. Soc., **110,** 123–129.

It is shown that a series of linear functions of serial correlation coefficients, which are in fact large sample distributions of partial correlations, can be used to test autoregressive schemes. It is also shown that superposed variations can be tested simultaneously.

49. Quenouille, M. H. 1948. *The joint distribution of serial correlation coefficients.* Ann. Math. Statist., **19.** (In the press.)

The joint distribution of serial correlation coefficients defined circularly is investigated both when these are corrected and uncorrected for the mean. An exact distribution is obtained for the former case while an integral approximation is obtained in the latter.

50. Quenouille, M. H. 1948. *The analysis of covariance and non-orthogonal comparisons.* Biometrics, **4.** (In the press.)

It is shown that when deviations from orthogonality are small, such as sometimes occur in field and animal experimentation and also in survey work, the usual process of fitting constants can be greatly simplified by the use of covariance analyses.

51. Quenouille, M. H. 1948. *Problems in plane sampling.* Ann. Math. Statist. (In the press.)

The relative accuracy of different methods of sampling an area are investigated mathematically and expressions are derived for the types of correlation functions which normally occur. By this means the relative accuracies of systematic and stratified random sampling are investigated under different conditions. Numerical examples of the various methods of sampling are given.

52. Quenouille, M. H. 1948. *The evaluation of probabilities in a normal multivariate distribution with special reference to the correlation ratio.* Edin. Math. Soc. (In the press.)

The large-sample distribution function of the correlation ratio is obtained and reduction formula and methods of evaluation are given.

53. Quenouille, M. H. 1948. *A technique for the quantitative estimation of soil micro-organisms.* Statistical appendix to a paper by P. C. T. Jones and J. E. Mollison. J. Gen. Microbiol., **2,** 65–68.

It is shown that the distribution of bacteria per colony is logarithmic, the distribution of colonies per plate is Poisson and consequently that the distribution of bacteria per plate is negative binomial. Mathematical reasons for this are given and the appropriate numerical methods of analysis are investigated.

54. Yates, F. 1947. *The analysis of data from all possible reciprocal crosses of a group of strains.* Heredity, **1,** 287–301.

The paper describes the analysis of data obtained in plant breeding work when all possible reciprocal crosses between different lines are made. The cases discussed are: self-sterility, no self-sterility, self-sterility with incompatibility within groups of lines. The last case is illustrated by a numerical example.

55. Yates, F. 1947. *The analysis of contingency tables with groupings based on quantitative characters.* Biometrika, **35,** 176–181.

The paper deals with the analysis of a p x q contingency table in the case in which one or both groupings are based on characters which are either directly quantitative or are in the form of gradings which can be regarded as having an underlying quantitative basis. The method of analysis is illustrated by a numerical example.

56. Yates, F. 1948. *Systematic sampling.* Phil. Trans. (In the press.)

This paper gives an account of the results of an investigation into one-dimensional systematic sampling, i.e., the sampling of sequences of quantitative values by the use of sampling points equally spaced along the sequence. New methods, using what are termed partial systematic samples, are evolved for estimating the systematic sampling error from short sections of sequences of completely enumerated numerical material. Simple end-corrections are proposed for eliminating the errors, due to trend, which are otherwise inherent in randomly located systematic samples. It is demonstrated that it is impossible to make any fully reliable estimate of the sampling error from the systematic sampling results themselves, though if the continuous components

of variation are not too marked, the sum of sets of terms taken alternately positive and negative, with suitable end adjustments, will provide a moderately satisfactory estimate, which will always be an overestimate provided there are no periodicities. This estimate is substantially better than the customary estimate based on successive differences. In other cases supplementary sampling is required to furnish an estimate of error, and methods are described whereby estimates can be derived from supplementary samples at half spacing, or at half and quarter spacing. The performance of systematic sampling is investigated theoretically for certain mathematical functions, and also by the numerical analysis of certain numerical sequences. The relation between the gain in precision and the gain in efficiency is evaluated.

REPORTS OF STATISTICAL INVESTIGATIONS

57. Anscombe, F. J., and Singh, B. N. 1948. *Limitation of bacteria by micro-predators in soil.* Nature, **161,** 140.

An analysis of the edibility of 87 strains of soil bacteria, of various types, by eight micro-predators. These micro-predators show some association in choice of prey, as if some bacterial strains are more intrinsically edible to the micro-predators than others.

58. Boyd, D. A., and Mathison, I. 1947. *Fertiliser application: findings of the Survey of Fertiliser Practice.* Agriculture, **54,** 325–328.

A summary is given of information on the use of combine drills obtained by the Survey of Fertiliser Practice. Only in the Eastern and South-Eastern provinces was more than half the phosphate fertiliser applied by combine drill, and even in these provinces combine drills were relatively uncommon in some of the more backward districts. In the west and north of the country the distribution of combine drills was sporadic, but generally speaking they were used on only a very small percentage of the farms. In all districts there was a marked tendency for the combine drills to be employed on the larger farms. While farms using combine drills used much the same total amount of fertiliser as farms which broadcast their fertiliser, the proportion of the acreage dressed was higher by about one-third on the combine drill farms.

The only surveyed area where combine drilling of root crops was at all common was the fen part of Huntingdonshire and the Isle of Ely, where a considerable proportion of the carrots, sugar beet and mangolds are drilled in this way.

SUMMARIES, REVIEWS, ETC.

59. Yates, F. 1947. *The influence of agricultural research statistics on the development of sampling theory.* Paper read at International Statistical Conference, Washington. (In the press.)

60. Yates, F. 1947. *Technique of the analysis of variance.* Nature, **160,** 472 (correspondence).

61. Yates, F. 1948. Thionet, P. *Methodes statistiques modernes des administrations fédérales aux Etats-Unis.* (Review.) Nature, **161,** 153.

Department of Plant Pathology

BOOK

62. Bawden, F. C. 1948. *Plant diseases.* Edinburgh, Nelson.

GENERAL ARTICLES

63. Bawden, F. C. 1948. *Some implications and limitations of recent work on plant viruses.* Proc. 4th Inter. Cong. for Microbiology.

64. Sheffield, F. M. L. 1948. *The virus in the plant cell.* Proc. 6th Inter. Cong. for Exptl. Cytology, Stockholm.

65. ————. 1948. *Some cytological studies of virus infected plants.* Proc. 7th Meeting E. M. group of the Instit. Phys.

66. Garrett, S. D., and Buddin, W. 1947. *Control of take-all under the Chamberlain system of intensive barley growing.* Agriculture, **54,** 425–26.

67. Watson, M. A. 1947. *Some aspects of the epidemiology of the yellows and mosaic diseases of sugar beet.* Prof. Conf. Int. de Rech. Betteraveries.

RESEARCH BULLETIN

68. Doncaster, J. P., and Gregory, P. H. 1948. *The spread of virus diseases in the potato crop.* A. R. C. Report series No. 7, London H.M. Stationery Office.

RESEARCH PAPERS

69. Bawden, F. C., and Crook, E. M. 1947. *Some properties of potato virus* X *in leaf extracts made in different ways.* Brit. J. Exp. Path., **28**, 403.

By incubating fibrous residues from leaves infected with potato virus X with enzymes from the alimentary tract of snails, as much virus is obtained as occurs in sap. About 4 per cent. of the virus extracted by snail enzymes is released by grinding the fibre finely in a triple-roller mill.

The virus in the different kinds of extracts does not differ greatly in infectivity, but the sizes of particles vary widely. The particles in mill extracts are short and give somatic-type precipitin reactions. In snail extracts, the particles are greatly elongated; in freshly-extracted sap particle length is variable but the average is greater than in mill extracts; both extracts give typical flagellar type precipitin reactions. The virus particles in sap vary in length and readily aggregate linearly.

Incubating mill extracts with healthy plant sap or trypsin causes the small particles to aggregate and changes their precipitin reaction from somatic to flagellar type.

Virus X in mill extracts or in purified preparations, but not in sap, is inactivated by incubation with pH 7 phosphate buffer and chloroform. This inactivation is prevented by snail enzyme preparations, healthy leaf sap and some other protein-containing solutions.

The virus content of infected plants varies with different hosts and virus strains. The largest was found with X^k in tomatoes, where the virus amounted to 2 per cent. of the dry weight of the leaves. There is no unequivocal evidence on either the size of the particles as they exist in the host cells or the relationship between the virus occurring in sap and that remaining in the fibrous residues.

70. Bawden, F. C., and Kleczkowski, A. 1948. *Variations in the properties of potato virus* X *and their effects on its interactions with ribonuclease and proteolytic enzymes.* J. Gen. Microbiol., **2**, 173.

When concentrated by precipitation with acid and salts, or by high-speed centrifugation, potato virus X tends to become insoluble though still remaining infective and serologically active. This greatly complicates purification and no method was found that could be relied upon to give good yields of virus with constant properties. Insolubility is correlated with the aggregation of virus particles to form long threads that become entangled, but it is probable that combination of the particles with some cell constituents is also concerned.

Insoluble preparations dissolve slowly when incubated with pH 7 boric acid buffer, and rapidly in the presence of trypsin and chymotrypsin. Both of these enzymes hydrolyse virus X, chymotrypsin being more effective, but different strains of the virus vary in susceptibility.

Ribonuclease readily hydrolyses the nucleic acid derived from virus X, but seems to have no enzymic action on the active virus. When mixed with the virus, the enzyme combines with it and reversibly inhibits infectivity. At pH 7 the addition of ribonuclease to soluble virus preparations causes loss of anisotropy of flow, a fall in precipitin titre, and the production of an insoluble complex. Incubation at pH 7·5 with boric buffer slowly dissolves the complex and restores the original properties of the virus; the rate of re-solution is increased by the presence of trypsin. Some preparations of the virus were partially decomposed by incubation with boric buffer, and sometimes the rate of decomposition was increased in the presence of ribonuclease.

71. Bawden, F. C., Kassanis, B., and Roberts, F. M. 1948. *Studies on the importance and control of potato virus* X. Ann. Appl. Biol., **35**, 250.

The success of seed certification schemes in controlling the aphis-transmitted viruses that cause leaf roll and rugose mosaic has greatly

increased the relative importance of potato virus X, in spite of the value of such schemes in reducing the prevalence of the most virulent strains. Virus X occurs throughout commercial stocks of most varieties and is responsible for many of the uncertainties and difficulties encountered in field inspections, for the production of leaf symptoms by many strains depends on the weather. Also, the predominating virus strain in a stock may change from season to season.

Methods of testing for the presence of avirulent strains in potatoes are described. These include transmission to suitable indicator plants, plant protection tests, and serological methods. The virus content of different parts of the plant varies widely, but in all is high enough for transmission to indicator plants at all times of the year. The virus content of immature tubers is too low to give a precipitin reaction, but extracts from developing sprouts contain nearly as much as those from foliage, and can be used reliably.

Infection of virus-free stocks of the varieties Majestic and Arran Banner with four different strains of virus X reduced their yields by amounts varying from 5 per cent. to 24 per cent. Scotch Stock Seed Majestic, however, cropped better than the virus-free seed, and the need for considering additional factors to freedom from viruses when selecting clonal lines for propagation is stressed.

Virus X was not transmitted by cutting healthy tubers with a knife previously used to cut infected ones, and cut tubers whose storage parenchyma was rubbed with infective sap gave rise to virus-free plants. Infection occurred when sprouts were rubbed with infective sap and the virus also spread from infected to healthy sprouted tubers stored in the same sack.

Spread of the virus under natural conditions is slow and it is concluded that the maintenance of virus-free stocks under commercial conditions is feasible, provided that precautions are taken to prevent contact with infected plants. The relative importance of volunteer plants and other sources of infection is discussed, and methods of testing the virus-free stocks are suggested.

72. Bawden, F. C., and Kassanis, B. 1947. *The behaviour of some naturally occurring strains of potato virus Y.* Ann. Appl. Biol., **34**, 503.

Potato virus Y was obtained from field crops of potatoes in many strains which differed widely in virulence and caused diseases in the variety Majestic ranging from severe leaf-drop-streak to mild mosaic. The symptoms caused by these strains in seven potato varieties and tobacco are described and compared with those caused by the serologically related potato virus C. No changes were noted in the behaviour of any of the strains over three years, during which they were transmitted to many different plants.

Potato virus C was not transmitted by *Myzus persicae*, the most efficient vector of other strains of virus Y. Nor was virus C transmitted by 11 other species of aphides, 8 of which transmitted virus Y. The efficiency with which different species acted as vectors of virus Y varied greatly, and it is suggested that in some species only occasional individuals can transmit.

Possible mechanisms for the evolution of viruses C and Y are indicated, and the effects of changes in virus, vector and host, on the prevalence of insect-transmitted viruses are discussed.

73. Broadbent, L. 1947. *Aphides overwintering as viviparae in roo clamps.* Ent. Mon. Mag., **83**, 178.

A note recording a new overwintering site for *Myzus persicae* and other aphides.

74. Broadbent, L. 1947. *An analysis of captures of Aphididae (Hemiptera) in a light trap.* Trans. R. Ent. Soc. Lond., **98**, 475–90.

Four years' captures of aphides in a light trap are analysed, on arithmetic and logarithmic bases, month by month and throughout the night. It is shown that aphides were flying during the night in each month from May to November. An attempt is made to correlate the captures of one summer with the various meteorological factors prevailing; activity was positively correlated with the maximum temperature of the previous day and with the evening reading of the dew point; it was negatively correlated with the wind force of the previous afternoon, and wind direction also had a significant effect. Population changes from year to year were probably dependent to a great extent on the summer rainfall, the population being lower in wet years.

75. Broadbent, L., and Hull, R. 1947. *Aphides in root clamps.* Agriculture, **54**, 319–22.

A survey of mangold and swede clamps infested with aphides is described. The numbers of *M. persicae* in the clamps was affected by harvesting and clamping methods. The potential danger of infested clamps as sources of spring migrant aphides is stressed, especially as sugar beet yellows virus is common also in mangolds.

76. Garrett, S. D. 1948. *Soil conditions and the take-all disease of wheat. IX. Interaction between host plant nutrition, disease escape, and disease resistance.* Ann. Appl. Biol., **35**, 14–17.

In a field experiment the Disease Rating of the roots of barley plants suffering from take-all was reduced by application of nitrogen, and by a combined dressing of phosphate and potash. This reduction is attributed to the fact that manuring enables the cereal plant to produce new crown roots more quickly than *Ophiobolus graminis* can infect them. In an earlier pot culture experiment, operation of this disease escape mechanism was inadvertently reduced to a minimum by inoculating plants at the crown, and by environmental conditions exceptionally favourable to infection (sand culture and relatively high temperatures in the glasshouse). Under these conditions, not only was root Disease Rating as high in the series receiving a full supply of nutrients (NPK) as in that receiving only one-third the full amount, but it was even reduced, almost to one-half, in the series receiving one-third nitrogen in the presence of full phosphate and potash (PK 1/3 N). It is concluded, therefore, that an increase in nitrogen supply may increase the intrinsic susceptibility of individual roots to infection, at the same time as it promotes disease escape and increased yield of the whole plant.

77. Garrett, S. D., and Mann, H. H. 1948. *Soil conditions and the take-all disease of wheat. X. Control of the disease under continuous cultivation of a spring-sown cereal.* Ann. Appl. Biol., **35**, 435-442.

In a field experiment on the control of take-all at the Woburn Experimental Station, winter wheat was followed by two consecutive crops of spring-sown barley. Samples of the barley crop were taken from the 48 plots of the experiment in 1945 and 1946, for estimation of root Disease Rating, and grain yields were also recorded. A comparison of six autumn treatments of the stubble has shown that treatments affecting the available nitrogen content of the soil exercised a predominant effect upon incidence of take-all in the following crop. Two effects of nitrogen applied in autumn have been distinguished: (1) an immediate effect, in assisting survival of *Ophiobolus graminis* in infected root and stubble residues; (2) a deferred effect, in promoting disease escape of the following crop. Ploughing-in straw in autumn increased the incidence of take-all, presumably because the adverse deferred effect of decomposing straw in locking-up available nitrogen and withholding it from the following crop outweighed its beneficial immediate effect in helping to starve-out *O. graminis*, by depriving the fungus of nitrogen. The autumn growth of undersown trefoil (*Medicago lupulina*) on the stubble land seemed to be entirely beneficial; active growth of the legume appeared to assist in starving-out *O. graminis*, and nitrogen was released by decomposition of the trefoil in the soil after spring ploughing in time to benefit the barley crop immediately following.

78. Gregory, P. H. *de Bary's description and specimen of* Peziza fuckelinana. Trans. Brit. Mycol. Soc. (In the press.)

Interest in *Sclerotinia Fuckeliana*, described by de Bary as the perfect stage of *Botrytis cinerea* on vine, is revived by the production of apothecia in pure cultures by Drayton and Groves. The identification of these apothecia has been hindred by lack of information on de Bary's fungus, the reference usually cited as a description being a *nomen nudum*.

The various descriptions of this fungus are cited, including a detailed account and figure by de Bary, which appear hitherto have been overlooked. Photographs are also given of de Bary's slide of *S. Fuckeliana* from the British Museum (Natural History), which evidently constitutes the type specimen. The information now available should help to determine the position of apothecia produced in pure culture.

79. Gregory, P. H. *The operation of the puff-ball mechanism of* Lycoperdon perlatum *by raindrops shown by ultra-high-speed Schlieren cinematography.* Trans. Brit. Mycol. Soc.

Spore discharge from puff-balls of the *Lycoperdon perlatum* type can be brought about by impact of water drops with the flattened papery top of the endoperidium. Rain drops of 1 mm. diameter or over, and rain-drip from trees are adequate to operate the mechanism. Analysis of the operation by ultra-high-speed photographs shows that the puff reaches a height of a centimetre in approximately one hundredth of a second after impact. The velocity of the puff on emerging from the ostiole is of the order of 100 cm. per second.

The endoperidium of *L. perlatum* is normally waterproof and ejection continues under humid conditions. Estimates, made from meteorological data, show that a fruit body must be operated many thousands of times in a season. It is concluded that rain drop impact is efficient in liberating spores from *L. perlatum*.

80. Hull, R. 1947. *Healthy sugar beet.* Agriculture, **54**, 7–21.

Practical measures which may be taken to avoid disease infection in sugar beet crops are described.

81. Hull, R., and Watson, M. A. 1947. *Factors affecting the loss of yield of sugar beet caused by beet yellows virus. II. Nutrition and variety.* J. Agric. Sci., **37**, 301.

The losses caused by infection increased proportionally as the mean yield increased through fertiliser applications. Fertiliser treatments did not greatly affect the rate of spread of the disease. None of the commercial varieties or the breeders lines which were tested were found to be materially more tolerant than others to the virus.

82. Kassanis, B., and Kleczkowski, A. 1948. *The isolation and some properties of a virus-inhibiting protein from* Phytolacca esculenta. J. Gen. Microbiol., **2**, 143.

An inhibitor of plant viruses can be isolated from the sap of *Phytolacca esculenta* by differential precipitation with ethanol followed by adsorption on celite and elution with 10 per cent. NaCl. Purified preparations contain 14-15 per cent. nitrogen and 8-12 per cent. carbohydrate, and the inhibitor is probably a glycoprotein. Denaturation leads to loss of inhibiting power. The protein is unaffected by pepsin and trypsin, unless denatured.

The glycoprotein is isoelectric at about pH 7. It can combine with tobacco mosaic virus, and when salt-free solutions of the two are mixed in certain proportions at pH values between their isoelectric points it precipitates the virus in the form of paracrystalline threads. The glycoprotein also precipitates tomato bushy stunt virus.

When added to several plant viruses the glycoprotein causes an immediate reduction in infectivity, but has no effect on a bacteriophage. Non-infective mixtures regain infectivity when diluted. No evidence was found for a combining ratio of virus to inhibitor necessary to cause loss of infectivity. The mechanism of virus-neutralization is discussed.

83. Kassanis, B., and Selman, I. W. 1947. *Variations in the reaction of White Burley tobacco to strains of tobacco mosaic virus.* J. of Pom. and Hort. Sci., **23**, 167.

White Burley tobacco exists in two distinct lines as shown by reactions to some strains of tobacco mosaic virus. The two are similar morphologically, but one line produces necrotic local lesions with tomato aucuba mosaic virus whereas the other line produces a systemic yellow mottle. In the lines in which tomato aucuba mosaic produces necrosis some other strains of tobacco virus also react necrotically.

84. Kleczkowski, A. 1948. *Proteolytic activity of preparations of crystallized ribonuclease.* Biochem. J., **42**, 523-27.

Crystalline preparations of ribonuclease invariably possessed proteolytic activity, which varied in amount in different preparations. The proteolytic and ribonuclease activities occur in somewhat different pH zones, and incubation between pH 4·0 and 4·5 gives ribonuclease activity alone, though in this zone it is far from its optimum.

By heating at pH 7·0–7·5 in specified conditions, the proteolytic activity can be greatly reduced or destroyed, while leaving between 80 per cent. and 30 per cent. of the original ribonuclease activity.

Ribonuclease is susceptible to both pepsin and chymotrypsin, but it is hydrolysed much more repidly by pepsin. The proteolytic enzyme present in crystalline preparations of ribonuclease also hydrolyses ribonuclease.

85. Roberts, F. M. 1948. *Experiments on the spread of potato virus X between plants in contact.* Ann. Appl. Biol. **35,** 266.

Experiments on the spread of five strains of potato virus X were made with seven potato varieties and with tomato plants both under glass and in the field. Spread by leaf contact between healthy and infected plants was confirmed and it was also found that spread could occur between plants whose only contact was below ground.

The rate of spread was much greater in tomato than in potato plants, and virulent strains of the virus, which achieve a high concentration in infected plants, spread more rapidly than avirulent strains. In only one experiment with potatoes did more than 10 per cent. of the healthy potato plants exposed to infection become infected during one season.

Datura stramonium and tomato plants became infected when growing in soil containing sap or residue from X-infected plants.

It was common in the field for potato plants whose foliage gave no reaction for virus X at the end of the season to yield a mixed progeny of healthy and infected tubers. Such infections are thought to result from underground spread.

Attempts to transmit virus X from infected to healthy potatoes by means of *Rhizoctonia solani* failed. No examples of infection were found except when healthy plants came into direct contact with sources of the virus.

Department of Biochemistry

86. Robertson, Noel, and Macfarlane, Ian. 1946. *The occurrence of perithecia of the oak mildew in Britain.* Trans. Brit. Myc. Soc., **24,** 119–20.

87. Bremner, J. M., Heintze, S. G., Mann, P. J. G., and Lees, H. 1946. *Metallo-organic complexes in soil.* Nature, **158,** 790.

88. Heintze, S. G., and Mann, P. J. G. 1946. *Divalent manganese in soil extracts.* Nature, **158,** 791.

89. Heintze, S. G., and Mann, P. J. G. 1947. *Soluble complexes of manganic manganese.* J. Agric. Sci., **37,** 23.

90. Holden, M. 1948. *An alkali producing mechanism in macerated* leaves. Biochem. J., **42,** 332.

91. Holden, M., and Tracey, M. V. 1948. *The effect of fertilisers on the levels of Nitrogen Phosphorus, Protease and Pectase in healthy tobacco leaves.* Biochem. J., **43,** 147.

92. Holden, M., and Tracey, M. V. 1948. *The effect of infection with tobacco mosaic virus on the levels of Nitrogen, Phosphorus, Protease and Pectase in tobacco leaves and on their response to fertilisers.* Biochem. J., **43,** 151.

93. Lees, H. 1947. *A simple automatic percolator.* J. Agric. Sci., **37,** 27.

94. Lees, H., and Meiklejohn, J. 1948. *Trace elements and nitrification.* Nature, **161,** 398.

95. Paterson, J. S., Pirie, N. W., and Stableforth, A. W. 1947. *Protective antigens isolated from Brucella abortus.* Brit. J. Exp. Path., **28,** 223.

96. Pirie, N. W. 1947. *The state of viruses in the infected cell.* Cold Spring Harbour symposia on quantitative biology, **9,** 184.

97. Pirie, N. W. 1947. *What is a dialysate?* Nature, **160,** 198.

98. Pirie, N. W. 1947. *Leaf protein.* Food Manufacture, **22,** 493.

99. Pirie, N. W. 1948. *The nature and development of life and of our ideas about it.* Modern Quarterly, **3,** 82.

100. PIRIE, N. W., and HADIDIAN, Z. 1948. *The preparation and some properties of hyaluronic acid from human umbilical cord.* Biochem. J., **42,** 260.

101. PIRIE, N. W., and HADIDIAN, Z. 1948. *The effects of serum and of hyaluronic acid derivatives on the action of hyaluronidase.* Biochemical J., **42,** 266.

102. TRACEY, M. V. *A possible role of d-amino-acids.* Biochem. Symposia, **1,** 89.

103. TRACEY, M. V. 1948. *Leaf protease of tobacco and other plants.* Biochem. J., **42,** 281.

104. TRACEY, M. V. 1948. *A manometric method for the estimation of small quantities of uronic acids.* Biochem. J., **43,** 185.

PUBLICATIONS IN THE PRESS

105. CROOK, E. M., and HOLDEN, M. *Some factors affecting the extraction of nitrogenous materials from leaves of various species.*

106. PIRIE, N. W. *The development of our ideas on the nature of viruses.*

107. PIRIE, N. W. *The combination of viruses with other materials in the infected cell and in extracts.*

108. TRACEY, M. V. *Human biochemical genetics.*

109. TRACEY, M. V. *Proteins and life.*

Department of Entomology

110. BARNES, H. F. 1947. *Periodic Fluctuations in the Prevalence of the Wheat Blossom Midges.* J. Animal Ecol., **16, 74–5.**

A note giving details of the rhythmic fluctuations in the numbers of the wheat blossom midges infesting the wheat on Broadbalk during the twenty years 1927–46. There have been two major peaks of infestation in 1931 and 1946 with two minor peaks in 1935 or 6 and 1941.

111. CERNOSVITOV, L., and EVANS, A. C. 1947. *Lumbricidae, No. 6 of Synopses of the British Fauna.* The Linnean Society, 36 pp.

Descriptions of and key to the British species.

112. EVANS, A. C., and GUILD, W. J. MCL. 1947. *Studies on the relationships between earthworms and soil fertility. I. Biological studies in the field.* Ann. Appl. Biol., **34,** 307–330.

Changes in the seasonal activity of several species of earthworms have been followed in a permanent pasture field for 18 months, 1945–6. The two soil conditions which chiefly determine activity are temperature and moisture. Other factors are the occurrence of an obligatory diapause in the two species *Allolobophora nocturna* and *A. longa*, and changes in population in *A. chlorotica* and *Lumbricus terrestris*.

Soil temperature and soil moisture also determined the weight of soil thrown up in the form of wormcasts during autumn, winter and spring. It is suggested that only two species, *A. nocturna* and *A. longa* are responsible for wormcasts and that the other four common species present play little or no part in this activity.

At Rothamsted it was found that the previous agricultural history of the field is an important factor in determining the fauna. Old permanent pasture is characterized by a high percentage of *A. nocturna* and a rather lower percentage of *A. caliginosa*. Ploughing old permanent pasture and reseeding to grass after 1 or 2 years arable reduces the proportions of *A. nocturna* and *A. caliginosa* and increases that of *Eisenia rosea*. Arable fields have *A. chlorotica* as the dominant species and pasture fields 2–7 years grass after many years of arable farming still show a high percentage of *chlorotica* and a low proportion of *A. nocturna*.

A survey of the Carse of Stirling, Scotland, showed that soil type is also an important factor in determining the earthworm fauna. *A. caliginosa* was the dominant species on the three soil types studied, but the subdominant species varied. On clay soil, *A. longa* was subdominant; on loam, *A. longa* and *L. rubellus*; on sandy soil, *A. longa, L. rubellus* and *A. chlorotica*. The dominant species of pasture land at Rothamsted, *A. nocturna*, was not found at Stirling.

113. Evans, A. C. 1948. *II. Some effects of earthworms on soil structure.* Ann. Appl. Biol., **35**, 1-13.

The weight of wormcasts thrown on to the surface of eight fields of differing agricultural history depends on the numbers of *Allolobophora longa* Ude and *A. nocturna* Evans present and also on the mean size of the individuals of these two species. The weight of wormcasts produced per acre per annum on the different fields varied from 1–25 tons, and it is calculated that from 4–36 tons of soil per acre per annum pass through the alimentary tracts of the total population of earthworms present. The percentage pore space of a soil containing a high population of worm-casting species is much greater than that of a field with a high population of worms which do not produce wormcasts. The amount of coarse sand relative to silt and clay increases appreciably with depth in two old pastures; this distribution is probably a result of the long continued activity of earthworms.

114. Guild, W. J. McL. 1948. *III. The effect of soil type on the structure of earthworm populations.* Ann. Appl. Biol., **35**, 181-192.

Sampling on several soil types, in Scotland, have shown that the earthworm populations differ in number and composition. Light and medium loams carry higher populations than the heavier clay or more open alluvial or sandy-gravel types. The genus *Allolobophora* is the most numerous on all types, *A. caliginosa* being the dominant species. *The Lumbricus* spp. are relatively more numerous on the alluvial and sandy-gravel types.

Natural hill pasture contains a smaller population than limed and fertilised pasture, and the species present are mainly small types. As natural pasture is brought under agricultural treatment the population increases and species typical of good pasture land become established.

115. Evans, A. C., and Guild, W. J. McL. *IV. The life-cycles of some British earthworms.*

The rate of cocoon production differs considerably from species to species and is greatly affected by soil temperature, moisture and the food supply of the adult worms. Only two out of fourteen species studied frequently produced more than one worm per cocoon and twins were only recorded once in many hundreds of observations on four species of the genus *Lumbricus*.

116. Evans, A. C., and Guild, W. J. McL. *V. Field populations.* Accepted for Ann. Appl. Biol.

The ploughing of a permanent pasture in spring was not followed by a reduction of the earthworm population during the first six months. Further arable cultivation does greatly reduce the population. Leys four to seven years old carry a total population similar to that of permanent pastures but with differing proportions of certain species. Some trends in population changes during a period of nearly one year are described for five common species. The population of a permanent pasture did not show appreciable change for a period of nearly three years but that of a ley, in its first year following arable, showed a significant increase.

117. Evans, A. C. 1947. *Earthworms.* J. Bd. Greenk. Res., **7**, 49–54. A popular summary.

118. Evans, A. C. 1946. *A new species of earthworm of the genus* Allolobophora. Ann. Mag. Nat. Hist. Ser. 11, **13**, 98–101.

One of the commonest worms found on permanent pastures at Rothamsted was found to be a new species.

119. Evans, A. C., and Guild, W. J. McL. *The cocoons of British earthworms.* (In MSS.) *Some notes on reproduction in British earthworms.* (In MSS.)

Descriptions of the cocoons of seventeen species.

120. Evans, A. C. *On segment number and regeneration in earthworms.* (In MSS.)

Earthworms possess a characteristic segment number which is sometimes of systematic value. The mean segment number of field populations is sometimes lower than that of the true value as a result of damage by predators. Some species emerge from the cocoon with the full number of segments already formed, others with a lower number. A study of the mean number of segments possessed by field populations from different areas suggests that the degree of predator attack may vary considerably. It is

suggested that posterior regeneration does not occur in the following genera, *Lumbricus* and *Octolasium*, and possibly not in *Dendroboena*, *Eiseniella* and *Bimastus*.

121. Evans, A. C. *On some earthworms from Iowa.* (In MSS.)
The dominant species present were of European origin, one new species was described.

122. Evans, A. C. *The identity of earthworms stored by moles.* (In MSS.)
Earthworms stored by moles consist chiefly of *L. terrestris*.

123. Evans, A. C. *The burrow systems of earthworms.* (In MSS.)
Earthworms of the genus *Lumbricus* appear to inhabit simple U-shaped burrows until the available supply of food on the surface is exhausted. When this occurs they burrow extensively into the surface soil and drive burrows deeply into the subsoil. *A. caliginosa* burrows extensively in the surface soil even though ample supplies of food are present on the surface.

124. Evans, A. C. 1947. *New facts about earthworms.* The Countryman.
A popular resumé.

125. Evans, A. C. 1948. *Earthworms and the soil.* Discovery.
A popular resumé.

126. Evans, A. C. 1948. *Earthworms and the farmer.* Farming.
A popular resumé.

127. Williams, C. B. 1947. *The field of research in preventive entomology.* Ann. Appl. Biol., **34**, 175–185.
An important branch of agricultural Entomology is that which is concerned with the causes of insect outbreaks and the possibility of anticipating and preventing them. The problems concerned are the environment factors which affect birth rate, death rate, length of life, and movement. The field of research can be roughly divided into the following branches:—

Factors affecting the total population.
The Physical environment
Geology and Geography
Climate and weather
The Biological environment
Food supply
Parasites and Predators
Competition.
Factors affecting the distribution of populations.
Migration, or deliberate movement
Drift, or accidental movement by natural causes
Accidental distribution by human agency.

Each of them is briefly summarized with examples and an appeal is made for more extensive work in applied ecology of insects.

128. Williams, C. B. 1947. *The generic relations of species in small ecological communities.* Journ. Anim. Ecol., **16**, 11–18.
Evidence had previously been brought forward to show that in large groups of animals or plants the number of genera with 1, 2, and with 3 and more species are closely represented by the mathematical "logarithmic series". New evidence is here given to show that the same order exists in the genera and species of quite small ecological communities.
The logarithmic series has several mathematical properties of biological interest, including the possibility of calculating, for any population or sample, a factor known as the "Index of Diversity" which is common to all random samples from a single population. It is a measure of the extent to which the species are grouped into genera, and it is independent of the size of the sample. If the Index of Diversity is high, there are many genera in relation to the number of species; if the Index is low, there are fewer genera in relation to the number of species.
It thus becomes possible to compare the Index of Diversity in natural small or simple ecological communities, with that of the larger population from which these have been selected by nature. This has been done for a number of cases, including both animal and plant communities, and in every case from which significant results can be obtained the Index of Diversity in the small community is smaller than that of the larger fauna or flora.

The result therefore indicates that there are fewer genera in a small or simple community than would be expected in a sample of the same number of species selected at random—that is, independent of generic relationships—from the larger series. In other words, the evidence brought forward by this method indicates a selection by nature in favour of more than one species in the same genus rather than in favour of single species in different genera.

Bee Department

129. Butler, C. G. 1946. *Bee culture and research in the U.S.A.* Ann. Rept. Central Assoc. of B.B.K.A., 2–10.

A brief report on a visit made to North America and of bee research work in progress in the Federal and some State laboratories. Particular reference is paid to work on artificial insemination of queen honeybees; the resistance of certain strains of bees to American Foul Brood: European Foul Brood: the sulphonamide treatment for American Foul Brood.

130. Butler, C. G. 1947. *An introduction to Beekeeping.* Daily Mail School-Aid Booklet.

131. Butler, C. G. 1947. *Beehives.* Ministry of Agriculture and Fisheries Bulletin. (In the press.)

132. Butler, C. G. 1947. *Some trends of bee research to-day.* J. Dept. Agric. Scotland. (In the press.)

133. Milne, P. S. 1947. *Sulphonamide treatment of American Foul Brood.* Agriculture, **54**, 82–87.

A summary of the experiments with various sulphonamides that have been carried out at Rothamsted and at number of outside centres.

134. Ribbands, C. R. 1947. *Some foraging methods of individual honeybees.* (Prepared for publication.)

Observations made upon the movements and behaviour of individual honeybees when collecting food, particularly pollen, in a specially planted experimental garden. It is concluded that worker honeybees exhibit a pattern of trial and error learning of considerable complexity.

135. Synge, A. D. 1947. *Pollen collection by honeybees* (Apis mellifera). J. Animal Ecology, **16.**

A study of the species of plants from the flowers of which honeybees in an apiary on the Rothamsted Experimental Farm collected their pollen during 1945 and 1946. It was found that approximately 95 per cent. of all the pollen collected was obtained from about 20 species of plants and that the clovers alone yielded almost 50 per cent. The availability of pollen in various species of flowers was also investigated.

Department of Insecticides

136. McIntosh, A. H. 1947. *A dipping apparatus for estimating the toxicity of insecticides in liquid media.* Ann. Appl. Biol., **34**, 233–239.

An apparatus and a technique are described for the study of the effect of liquid insecticidal preparations by dipping insects in the toxic material. The method is applicable to quick-settling suspensions and quick-creaming emulsions as well as to solutions. Dipping is performed at constant temperature with end-over-end shaking; and the technique has the advantage over the other dipping methods that have been described in that handling of individual insects whilst wet is eliminated.

137. Lord, K. A., and Johnson, C. G. 1947. *The production of dermatitis by pyrethrum and attempts to produce a non-irritant extract.* Brit. J. Dermatology & Syphilis, **59**, 367–375.

The production of dermatitis in both men and women by continual application of pyrethrum creams is described.

The preparation of pyrethrin concentrates by chromatographic adsorption is also described. Tests on the irritant properties of these preparations suggest that petroleum ether and ethylene dichloride wash out the pyrethrins preferentially from a column of fullers earth which retains the dermatitis-producing factor. The amount of dermatitis producing factor present in some of the preparations appeared to be much lower than that contained in a commercial concentrate.

138. Bray, G. T., Harper, S. H., Lord, K. A., Major, F., and Tresadern, F. H. 1947. *The determination of the factor for pyrethrin I in the mercury method.*. J. Soc. Chem. Ind., **66**, 275–279.

The authors have examined in two series of experiments the effect of varying the conditions under which the reduction of Deniges reagent by chrysanthemum monocarboxylic acid is allowed to proceed. They have shown that both temperature and time of reaction influence appreciably the extent of the reduction; and have confirmed the result previously obtained by Graham and LaForge, that 1 ml. 0·01 M-potassium iodate solution is equivalent to 5·7 mg. pyrethrin I when the reduction takes place at 25 ± 2° for 1 hour. Differences of 5–6 per cent. of the general mean value were shown in the second series despite careful standardisation of conditions.

139. Harper, S. H., Potter, C., and Gillham E. M. 1947. *Annona species as insecticides.* Ann. Appl. Biol., **34**, 104–112.

By extraction and precipitation from several solvents the toxic principle present in *Annona reticulata* and *A. squamosa* seeds and roots has been concentrated up to one hundredfold. A preliminary chemical examination of this concentrate is described, leading to the conclusion that the toxicity is due to a glyceride or glycerides of a hydroxylated unsaturated acid or acids of high molecular weight.

These extracts have been examined for contact and stomach poison and ovicidal properties in a variety of media. When used as a contact insecticide against *Aphis fabae, Macrosiphoniella sanborni* and *Macrosiphum solanifolii*, the concentrate exhibited a toxicity of the same order as that of rotenone, but against *Oryzaephilus surinamensis* the toxicity was considerably less. As a stomach poison the ether extract was both toxic and repellent to *Plutella maculipennis* larvae, but was neither toxic nor repellent to *Diataraxia oleracea* larvae. Ovicidal tests against the eggs of *Plutella maculipennis* and of *Ephestia kuhniella* were inconclusive. The potency of this concentrate is therefore of a limited nature and although of roughly the same order as that of rotenone to certain aphides, it has neither the intensity of effect nor the range of insecticidal action of that compound.

PAPERS IN PRESS

140. Tattersfield, F., Potter, C., Lord, K. A., *et al. Insecticides derived from plants.* Kew Bulletin.

A number of plants, British, tropical and Chinese, have been tested for insecticidal activity.

(1) The earlier tests were all made with extracts of the ground up material, later it was found that the ground material itself could show considerable toxicity where little or none showed in an extract.

(2) When tested as extracts although some of the British plants possessed some insecticidal properties, none were of a sufficiently high standard to be worth further examination, with the possible exception of the fruits of *Euonymus europaeus*. In later tests as powder rhizomes and leaves of Winter aconite *Eranthis hyemalis* showed considerable insecticidal activity.

(3) Extracts of tropical plants showed some activity as contact and stomach poisons or as repellents but none approached in potency known plant or synthetic insecticides. When tested as powders, *Randia nilotica* (root) from Nigeria and *Randia dumetorum* from Ceylon showed considerable activity.

(4) Of the Chinese plants submitted to us, *Milletia pachycarpa* deserves most consideration as an insecticide of the Derris class although not so powerful in its toxic action as the most recent strains of *D. elliptica* root. The fact that the seed possesses insecticidal properties adds interest to this plant. The seeds should be easier to harvest than the roots. With this plant, too, notable differences in activity were found when extracts were compared with the ground up material. *Derris fordii* (root), *Tripterygium exesum* (root bark) and *Rhododendrum molle* (flowers) all showed considerable insecticidal activity as powders.

Some of the differences in effect between extracts and powders may be due to specificity but there seem to be other factors which cannot be as yet established, which we regard as important and hope to investigate.

141. Way, M. J., and Synge, A. D. 1948. *The effect of DDT and γ-BHC on bees.* Ann. Appl. Biol., **35**, 94-109.

Conclusions drawn from this work are that DDT on open blossom in the preparations used is safe to bees. There is always a danger that in a more highly activated form it may prove dangerous, since under laboratory conditions it was found to be rather more toxic as a stomach poison than Lead Arsenate. This should be remembered when the use of DDT on a large scale or on open blossom is necessary.

Field concentrations of BHC on open blossom are lethal to bees and may be harmful for at least three days after application. No repellency was noticeable and it is considered that the use of this insecticide in the field may be a serious danger to the foraging bee population. Since the speed of action is not sufficient to incapacitate contaminated workers before they return to the hive there is the further risk that nurse bees may be poisoned by contaminated pollen and nectar.

No experiments were carried out to determine the effect of BHC on honey bee larvae but preliminary work with DDT, which requires confirmation, suggests that this insecticide is not dangerous.

Certain wild bee workers have a susceptibility to both DDT and BHC comparable with that of honey bee workers but a notable resistance is shown by Bumble bee queens and drones.

142. McIntosh, A. H. 1947. *The relation of crystal size and shape to the contact toxicity of aqueous suspensions of DDT to* Tribolium castaneum *Hbst.* Ann Appl. Biol., **34**, 586–610.

Fairly coarse aqueous DDT suspensions can be made by the exchange of solvent method. By varying the method of preparation the mean size of crystal in suspension can be altered. The principles involved are outlined, and methods and apparatus are described for preparation of the following suspension types: colloidal DDT, a suspension containing elongated hexagonal plates, a suspension of somewhat elongated two-dimensional aggregates of plate-like crystals, and three suspensions of needle-shaped crystals of different lengths. All the DDT crystals are of the same fundamental crystal habit. These suspension types were selected to study the effect of both crystal size and shape on toxicity.

The suspensions were tested against *Tribolium castaneum* Hb. using a recently developed dipping technique. It was shown that the results obtained were independent of any operation peculiar to the technique.

Suspensions tested by a spraying method gave data similar to those obtained by dipping, except for certain anomalous results obtained where the crystals were considerably broken up in passing through the spray nozzle.

Toxicity differences were assessed by the probit method. The lines obtained for the crystalline suspensions were generally parallel to one another but the colloidal DDT gave a line differing in slope from the others.

The dipping tests showed that, within the range of crystal sizes up to about 400, toxicity increased with increasing needle length; breadth was less important but a suspension of needle-shaped crystals was as toxic as one containing considerably larger plate-shaped crystals at the same weight/volume concentration. Colloidal DDT was less toxic than any crystalline suspension. Thus, taking the median lethal concentration for $400-\mu$ needles as 100, the values for the other types were: for $120-\mu$ needles, 210; for plate aggregates $(240\times140-\mu)$, 260; for $40-\mu$ needles, 390; for $60\times15-\mu$ plates, 510; and for colloidal DDT, 1,700.

These differences in toxicity were paralleled by retention of greater amounts of DDT from the coarse suspensions than from finer ones; two extreme types were of almost identical toxicity, comparing the percentage kills produced by equal amounts of poison retained, and not by equal concentrations in suspension. The methods of carrying out these retention tests are described.

143. Stoker, R. I. 1948. *Experiments on the phytocidal properties of DDT and γ-BHC.* Ann. Appl. Biol., **35**, 110-122.

The experiments indicated that, while DDT might have deleterious effects on cucurbits, it was not otherwise seriously phytotoxic.

BHC, on the other hand, caused damage to a variety of plants. However, the concentrations used were not always necessarily those used in practice.

BHC also caused tainting of fruit and vegetables in some experiments.

144. Potter, C. *A modified apparatus for the estimation of the toxicity of contact poisons.* J. Econ. Ent.

An apparatus for examining the effect of contact insecticides based on that described in the Ann. Appl. Biol. (1941), **28,** No. 2, pp. 142–169, but embodying a number of modifications making for greater accuracy and ease of working is described, together with tests of its physical performance.

READY FOR PRESS

145. Lord, K. A. *The decomposition of DDT by alkaline materials.*

146. Lord, K. A. *The sorption of DDT and its analogues by chitin.*

147. Lord, K. A. *The effect of insecticides on the respiration of* Oryzaephilus surinamensis *L. An attempt to compare the speeds of action of a number of DDT analogues.*

148. Lord, K. A. *The toxicity of a number of DDT analogues and the four isomers of benzene hexachloride as contact poisons to* Macrosiphoniella sanborni *Gill. and* Oryzaephilus surinamensis *L.*

149. Way, M. J. *Laboratory experiments on the effect of insecticides, particularly DDT and BHC, on certain aphidophagous insects and their host relationships.*

150. Way, M. J. *A laboratory technique for the quantitative estimation of stomach poisons.*

151. Way, M. J., and Stoker, R. I. *Experiments on the persistence of the toxicity of DDT on foliage.*

152. Way, M. J., and Stoker, R. I. *The selection and rearing of test insects for use in laboratory studies on insecticides, particularly stomach poisons.*

WOBURN EXPERIMENTAL STATION

153. Mann, H. H., and Barnes, T. W. 1947. *The competition between barley and certain weeds under controlled conditions. II. Competition with* Holcus mollis. Ann. Appl. Biology, **34,** 252–266.

154. Mann, H. H. 1946. *Millets in the Middle East.* Emp. J. Expt. Agric., **14,** 208–216.

155. Mann, H. H. 1947. *Pulse grain crops in the Middle East.* Emp. J. Expt. Agric., **15,** 237–259.

GENERAL

156. Ogg, W. G. 1947. *Rothamsted Experimental Station.* Farming, **1,** 265.

157. Ogg, W. G. 1947. *Soils and health.* Advancement of Science, **IV,** 265. (Presidential Address to Section M (Agriculture) of the British Association, 1947.)

158. Garner, H. V. 1946. *The rotting of straw.* Farming, **1,** No. 3.

Publications of the Rothamsted Experimental Station

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"ARTIFICIAL FERTILISERS IN MODERN AGRICULTURE," by Sir E. J. Russell, D.Sc., F.R.S. Bulletin No. 28, Ministry of Agriculture and Fisheries, Third Edition, revised 1939. H.M. Stationery Office, or from the Secretary, Rothamsted Experimental Station, Harpenden. Cloth, 4/6 post free : or paper cover, 3/5 post free.

"WEEDS OF FARMLAND," by Winifred E. Brenchley, D.Sc., F.L.S., 1920. Longmans, Green & Co., 39 Paternoster Row, London, E.C.4. 12/6.

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